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DIMINISHING RETURNS IN AGRICULTURE

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DIMINISHING RETURNS IN AGRICULTURE

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BY

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PREFACE

The following essay is not a discussion of theories of diminishing returns, nor does it aim to describe their history and development. Rather, it represents an attempt to discover what light can be shed by the results of certain agricultural experiments on the problem of securing a more precise formulation of the conventional law of diminishing returns as applied to experimental agriculture.

This, however, is only the primary object. It addition to it, an endeavor is made in the present essay to discover the factors responsible for the logically demonstrable rise and fall of returns in agricultural enterprise. A third and final object is to show, by means of the presentation of some statistics of the past history of agricultural productivity and some arguments in refutation of certain views as to its future, the apparent lack of foundation for the belief in a temporal process of diminishing returns in agriculture.

Of these objects, only the first, perhaps, can be held to have been accomplished in any definite way. The second, and particularly the third, have involved the consideration of such complicated phenomena that their pursuit has led to what will no doubt seem to many to be nothing more than the presentation of some particular views on the problems under discussion. They have been here included, however, not only for the sake of completeness, but also because they are widely considered to be indispensable on the one hand for the understanding of present economic phenomena, and on the other for the study of the probable future course of the productivity of human labor.

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In the eight or nine years which have elapsed since this study was first undertaken, the author has received help from many persons. He desires chiefly to thank Professor W. M. Carruth of Hamilton College for an important mathematical suggestion, Professor H. L. Moore of Columbia University for pointing out to him some important previous discussions of the mathematics of diminishing returns, and Professor H. R. Seager of Columbia University for his kindly criticisms and for help in preparing the manuscript for publication.

TABLE OF CONTENTS

PAGE
PREFACE

CHAPTER I

The Problem of Diminishing Returns in Agriculture 5

CHAPTER II

The Tests of Diminishing Returns 9

CHAPTER III

Diminishing Physical Returns in the Sources of Power for Agricultural Operations 15

CHAPTER IV

Diminishing Physical Returns in the Application of Fertilizers, Seed and Cultivation to the Soil 24

CHAPTER V

Diminishing Physical Returns in Food Transformation by Farm Animals 32

CHAPTER VI

Anticlinal Profits in Agricultural Enterprise 50

CHAPTER VII

The Problem of Secular Diminishing Returns in Agricultural Development 56

CHAPTER VIII

Summary and Conclusions 67
BIBLIOGRAPHY 96
INDEX 99

CHAPTER I

THE PROBLEM OF DIMINISHING RETURNS IN AGRICULTURE

THE ideas of economists in regard to diminishing returns in agriculture have been commonly expressed in what is generally called "the law of diminishing returns". A typical statement of this law is the following one made three quarters of a century ago by John Stuart Mill:

> After a certain, and not very advanced, stage in the progress of agriculture, it is the law of production from land, that in any given state of agricultural skill and knowledge, by increasing the labor, the produce is not increased in an equal degree; doubling the labor does not double the produce; or, to express the same thing in other words, every increase of produce is obtained by a more than proportional increase in the application of labor to the land.[1]

The origin of this idea can be traced to the year 1815 when four English economists—Edward West, Robert Torrens, David Ricardo and Thomas Robert Malthus — expressed it independently and at almost the same time in their writings. The cause of this almost simultaneous enunciation of the proposition was undoubtedly the publication by two special committees of Parliament — one from each House—of reports which asserted a directly contrary doctrine. These committees had been appointed to investigate the wisdom of retaining the high duties on wheat which had been imposed in England during the Napoleonic wars. Representing, as they did, only the landholding classes, they naturally recommended the retention of the duties, for landowners were anxious to retain the large rents which the high grain prices arising out of the war had made it possible for them to secure. In their reports, however, the committees gravely stated that their only reason for recommending the retention of the duties was their conviction that only this would make it possible for England to keep the recognized advantages of intensive agriculture.

---

[1] Mill, J. Stuart, *Principles of Political Economy* (ed. Ashley, London, 1909), p. 177.

West was probably the first to denounce this reasoning. He argued that " in the progress of the improvement [i. e. intensification] of cultivation, the raising of rude produce becomes progressively more expensive ".[1] In other words, intensive agriculture was, in West's opinion, necessarily relatively unproductive agriculture, and England would be better off without it. He believed, however, that intensive agriculture could not be put off indefinitely, for population was growing, and increased population would necessarily require increased food supplies, and these could be secured only by more intensive agriculture. Thus, the natural growth of population necessitates more intensive agriculture, and, as a consequence, " The whole of the work bestowed on agriculture in the progress of improvement yields an actually diminished proportionate return ". [1]

The ideas of the other three economists were substantially similar to West's. Together, they expressed an idea which took such hold on the economists of the day that the law of diminishing returns, as the proposition was called, was almost immediately admitted to the canon of accepted economic principles. It was held to be as vital in understanding economic phenomena as is the law of gravity in the understanding of physical and astronomical phenomena.

---

[1] West, Edward, *Essay on the Application of Capital to Land,* quoted in Cannan, E., *Theories of Production and Distribution* (London, 1917), p. 157.

This enthusiasm has cooled with time, and present-day economists are much less certain of its nature and importance. A typical present statement of the law of diminishing returns is that of Alfred Marshall:

> Although an improvement in the arts of agriculture may raise the rate of return which land generally affords to any given amount of capital and labor; and although the capital and labor already applied to any piece of land may have been so inadequate for the development of its full powers, that some further expenditure on it even with the existing arts of agriculture would give a more than proportionate return; yet these conditions are rare in an old country: and except when they are present, the application of increased capital and labor to land will add a less than proportionate amount to the produce raised, unless there be meanwhile an increase in the skill of the individual cultivator. Secondly, whatever may be the future development of the arts of agriculture, a continued increase in the application of capital and labor to land must ultimately result in a diminution of the extra produce which can be obtained by a given extra amount of capital and labor.[1]

Although this statement may be regarded as typical of present definitions of the law of diminishing returns, many economists have attempted to improve it. The object has generally been to surmount one or more of the difficulties which this definition and others similar to it are supposed to involve. Some of these difficulties are, (1) the presence of too many qualifying clauses, (2) the use of several expressions of insufficiently precise significance, (3) the failure to make the definition broad enough to cover all the phenomena of diminishing returns.

---

[1] Marshall, *Principles of Economics* (London, 1910), p. 153.

Efforts to solve these and other difficulties have led to a great variety of definitions. In his *Value and Distribution* Professor Davenport was able to distinguish eleven different concepts of the law of diminishing returns.

Of these, he writes,

> such formulations of the law as promise significance or serviceability for economic purposes of any sort, competitive or collective, are three in number:
>
> 1. A dynamic and sociological generalization foretelling a diminution in the per-capita command of consumable goods, by reason solely of the society coming to contain more members, these being assumed to be unmodified in all relevant aspects.
>
> 2. A law in the dynamics of competitive economics; a forecast of changes in the relative distributive shares accruing to different agents and instruments in production technologically viewed, changes due solely to changes in the relative supply of these concrete factors; thereby changes in their relative value through the capitalization of their income-earning power; and thereby, also, *upon the supply side* (and for whatever the cost of production computation may be worth), and solely by reason of these distributive shares functioning as costs in competitive entrepreneur production, a forecast of the relative changes in the market prices of the various sorts of commodities technologically dependent in various degrees upon the use of these differently remunerated productive factors.
>
> 3. A static, competitive, entrepreneur law expressing the disadvantages accruing to the entrepreneur from any relative excess or defect in the quantities employed of any productive agent or agents, in view of the existing levels of compensation for these different agents—a law formulating the disadvantage from the unskilful combination of cost goods.[1]

Professor Fetter has a slightly different view of the most important separate aspects of the law. "In our view", he says, " there are at least three distinct problems: (1) technical proportion, the best mechanical or physical combination; (2) profitable proportion, the entrepriser's best combination of factors at existing prices; (3) diminishing returns, the socio-economic problem of the relation of population to resources."[1]

---

[1] Davenport, *Value and Distribution* (Chicago, 1908), p. 506.

The experimental and statistical data which will here be presented seem to fall most naturally into three groups which are apparently identical with those described above by Professor Fetter. The first of these groups includes all data relating to *physical, experimental* or *technical* diminishing returns. These data all result from experiments in which both input and output are physical substances and are measured in terms of such units as pounds, tons, yards, horsepower, etc. The second group contains all data as to diminishing returns of profit arising out of the profit-seeking activities of agricultural entrepreneurs. It can perhaps best be called *entrepreneurial* or *money* returns. The data in this instance arise from accounting and from statistics relating to profits rather than from experiment.

The third group of data relates to what will here be called *secular* diminishing returns. This means such returns as are indicated above in Professor Marshall's definition, namely returns diminishing from one period of time to another. To many economists the law of diminishing returns means this proposition that in the future the efforts of succeeding generations of men to produce food will become steadily less effective. Secular diminishing returns can be said to occur if the number of hours required to produce a given quantity of foodstuffs shows a steady tendency to increase, or if a growing proportion of the world's labor supply is necessary to produce enough food to avert starva-

[2] Fetter, *Economic Principles* (New York, 1918), p. 440, footnote.

tion. In view of the fact that no instances of secular diminishing returns seem to be available, the discussion of the subject in this essay will be limited to the presentation of some concrete material bearing on the arguments which support it.

Because of the fundamental differences between these three groups of data it will be necessary to treat them separately, and they are made the basis of the following chapters of this essay.

CHAPTER II

THE TESTS OF DIMINISHING RETURNS

THE problem of determining whether a given set of data relating to the efficiency of a productive process do or do not exhibit diminishing returns is one which can be solved only by reference to the type of phenomena involved. In the case of secular diminishing returns the test is least dubious. It consists by definition in the diminution as time passes of the average physical returns to agricultural labor. In view of the fact, however, that such a diminution might conceivably be compensated by an increase in the returns to non-agricultural labor, a more convincing test would be the diminution as time passes of the average physical returns to labor in general.

As for physical and money returns, the matter is more complicated. Many distinguished economists have apparently supposed that here too the test was to be found in the diminution of average returns. A minority of mathematical economists, however, have long protested that such a test would be inaccurate. As long ago as 1838 Augustin Cournot explained in his *Recherches sur les Principes Mathematiques de la Theorie des Richesses* that the differential coefficient of the law of cost of a commodity is a function "the form of which exerts very great influence on the principal problems of economic science". In a later passage he added, "Whenever it is a question of working agricultural lands . . the differential coefficient increases with the output ".[1] Since all the units of agricultural output may be assumed to sell at the same price, increasing cost is really identical with diminishing return, and as a consequence the test of diminishing returns, in the estimation of Cournot, would be the diminution of the differential coefficient of the law of return.

This was stated explicitly by Professor F. Y. Edgeworth in the following passage taken from an article contributed more than a half-century later to the *Economic Journal:* "I define the laws of increasing and decreasing cost thus. If $\phi(x)$ be the expense—or more generally the equivalent in money of the 'real cost'—of producing the quantity x of a certain commodity, the law of increasing cost holds, when $\frac{d_2 \phi}{d x^2}$ is *positive;* the law of decreasing cost when $\frac{d_2 \phi}{d x^2}$ is negative. . . . Decreasing and increasing returns will here be used as synonyms of increasing and decreasing cost." [2]

Because of the failure of economists to observe these distinctions, Professor Edgeworth in a later contribution to the *Economic Journal* explained them without resorting to the symbols of the differential calculus. "The law of increasing cost, synonymous with decreasing returns, holds good when the ratio of the last increment of cost to the last increment of produce is greater than the ratio of the penultimate increment of cost to the penultimate increment of produce." This definition, he says, is different from that of some distinguished economists who imply "that the law of increasing or decreasing cost holds good according as the ratio of total cost to total product increases or decreases with the increase of product." [3]

---

[1] Quotations from a translation by N. T. Bacon entitled *Researches into the Mathematical Principles of the Theory of Wealth* (New York, 1897).

[2] *Economic Journal,* March, 1897, p. 46, note 3.

[3] *Economic Journal,* June, 1899, pp. 293-4.

This statement was later clarified as follows: "When on the application of two successive equal doses of productive power, the increment of product due to the first dose is less than the additional increment due to the second, the law of increasing returns is said to act; and conversely it is a case of decreasing returns when the increment due to the first dose is greater than the increment due to the second."[1] A similar, but graphical test may be made as follows: If the inputs or outlays involved in the productive process be plotted as abscissas on a piece of rectangular coordinate paper, and the outputs or returns as ordinates, then diminishing returns will exist for that range of inputs within which the curve of output is concave toward the abscissas (or X-axis).

In these descriptions of the tests of diminishing returns which are mathematically accurate, Professor Edgeworth has set a standard beyond which it would be impossible to go for theoretical perfection. That the distinction between average returns and marginal returns, which he returned to in a still later contribution to the *Economic Journal*,[1] is a matter of the greatest practical importance will appear from a large number of comparisons of the two which will be made in the following pages.

Before going further it may be well to define certain expressions which will be used repeatedly in the treatment of experimental data relating to diminishing returns. *Total returns* will be used to signify the total products, outputs or returns corresponding to specific amounts of input or outlay. *Average returns* will mean the quotients obtained by dividing total outputs by the appropriate inputs. When an average return is expressed in terms of the percentage which it bears to the highest average return theoretically attainable, it becomes the familiar efficiency. *Marginal returns* will mean the ratio of an increment of output to a finite or infinitesimal increment of input which gave rise to it, when these increments are located at the margin of intensification of input.

---

[1] *Economic Journal*, Sept., 1911, p. 350.

It has been pointed out in the above quotation that Cournot and Edgeworth proposed to test the variation of marginal returns by means of the first derivative of the equation of the curve of total returns. In view of the fact that this equation is almost never available for actual productive processes, it will be necessary to discover some other test. Edgeworth proposed in addition the graphic test of observing the curvature of the curve of total returns. This, however, assuming that the shape of the curve of total returns is well established, indicates only whether returns are increasing or diminishing, and not at exactly what rate. To determine this important matter several methods are available. The simplest is to determine, by the process of subtracting from each total return the preceding one, what will be here called *Returns from Marginal Doses of Input.* This is illustrated in the following table.

COMPUTATION OF AVERAGE RETURNS AND OF RETURNS FROM MARGINAL DOSES OF INPUT

Input	*Return*	*Average Return*	*Return from Marginal Dose of Input*
1	1.88	1.88	1.88
2	2.58	1.29	.70
3	3.09	1.03	.51
4	3.50	.86	.41
5	3.85	.77	.35
6	4.15	.69	.30

The data in this table are imaginary and will be used in this chapter for illustrative purposes. It will be observed that while total returns increase throughout the range of the data, both average and marginal returns diminish, the latter falling the more rapidly of the two. This is due to the fact that average returns give as much weight to the highly productive initial inputs as to the relatively unproductive marginal ones, whereas marginal returns are free of any admixture with all inputs prior to the marginal ones. It is for this reason that marginal returns give a much more accurate idea of the variation of the efficiency of a productive process, and, in particular, are indispensable for the determination of how far it pays to carry input. Because of the large size of the doses, however, the above method of getting an idea as to the ratio of output to input at the margin leaves a good deal to be desired.

The greatest practical defect of this method is that it can only be used in the infrequent instances in which the increments of input are of unit size. Where they are irregular in size the most practical method is to determine what will here be called *average returns from marginal inputs*. This variety of marginal returns may be computed by the simple process of dividing the marginal increment of output by the marginal increment of input. This computation is illustrated in the following table.

COMPUTATION OF AVERAGE RETURNS FROM MARGINAL INPUTS

Total Input	*Total Output*	*Marginal Increment of Input*	*Marginal Increment of Output*	*Average Return from Marginal Input*
0.95	1.83	0.95	1.83	1.927
1.30	2.12	0.35	.29	.857
2.76	2.98	1.46	.86	.590
3.90	3.47	1.14	.49	.430
4.50	3.69	.60	.22	.367
6.00	4.15	1.50	.46	.306

A fairly close correspondence will be noted between the figures for average returns from marginal inputs with those for returns from marginal doses of input in the table on p. 18 above. This is due to the fact that the data in both tables were derived from the same imaginary productive process, that the doses and increments lie at substantially the same place in the increase of input, and that they were of the same order of size.

Both of these kinds of marginal returns are inadequate for the main purpose for which marginal returns are ordinarily desired, the determination, namely, of how far to carry input to secure the greatest profit. In solving this problem it may be laid down as axiomatic that the greatest profit may be secured by continuing to increase input as long as the increments of output produce a profit, however small, and that it cannot pay to carry input beyond this point. Taking the above table as an illustration, if we assume that the cost of a unit of input is 36.7% of the value of a unit of output, the increase of input from 3.90 to 4.50 units produces an increment of output which barely repays the cost of the increment of input. It certainly doesn't pay to carry input beyond this point.

Does it pay to carry it that far? The increment of input from 3.90 to 4.50 pays for itself *as a whole,* but since marginal returns are diminishing throughout the range of the data, it is certain that the first part of the increment produces a profit and the remainder a loss. Just where in this increment does it cease to pay to increase input? The table provides no means of answering.

To solve this problem we must have some means of determining the third sort of marginal returns, namely, *marginal rates of return.* A marginal rate of return may be defined as the rate of *increase of output with respect to input.* Compared with this rate, the two varieties of marginal returns which we have been considering are averages, returns from marginal doses of input being averages of marginal rates of return for successive doses of input, and average returns from marginal inputs being averages for irregular increments of input.

The computation of marginal rates of return is not difficult if we have the algebraic equation satisfied by the data as to inputs and total returns. It can be effected with the data used in this chapter, for these data were chosen because they satisfy the equation $y = 2\sqrt{x} - \frac{x}{8}$, inputs being x's, and outputs y's. Differentiating this equation, we get $\frac{dy}{dx} = \frac{1}{\sqrt{x}} - \frac{1}{8}$. Substituting in this equation values of x equal to the total inputs, we get the desired marginal rates of return. They are indicated in the adjoining table, in which for comparative purposes average returns from marginal inputs are also given. The marginal rates of return appear in the column to the right.

COMPARISON OF MARGINAL RATES OF RETURN WITH AVERAGE RETURNS FROM MARGINAL INPUTS

Total Input	*Total Output*	*Average Return from Marginal Input*	*Marginal Rate of Return*
0.95	1.83	1.927	.901
1.30	2.12	.857	.753
2.76	2.98	.590	.477
3.90	3.47	.430	.381
4.50	3.69	.367	.346
6.00	4.15	.306	.283

Just as, when marginal returns are diminishing, average returns from marginal inputs are smaller than average returns, so marginal rates of return are less than average returns from marginal inputs. The reason in each instance is the partial or entire elimination of the influence of the more productive earlier inputs.

The problem of determining how far it pays to carry input when a unit of input costs 36.7% as much as a unit of output can now be solved by interpolation in the column of marginal rates of return. It works out that 4.14 units of input is the point of greatest profit.

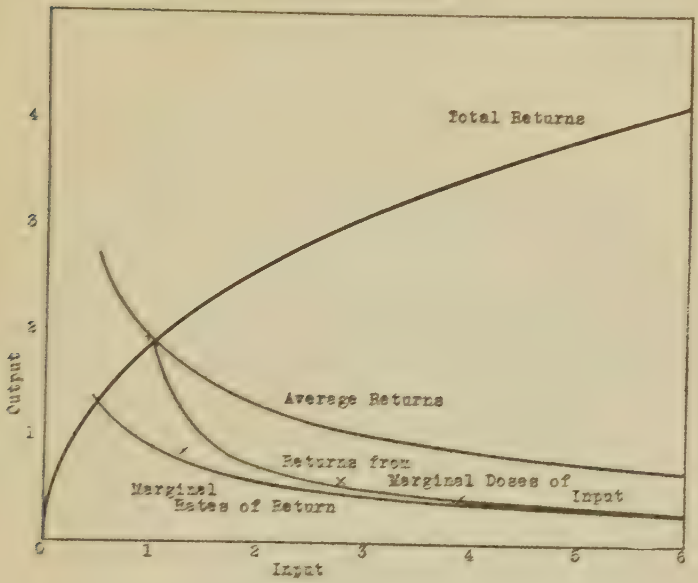
This method assumes rectilinear correlation between the datum points, and it is probable that a slight error has thus been introduced. This error can be eliminated by substituting directly the value .367 for $\frac{dy}{dx}$ in the equation of the first derivative, and solving for x. The result, 4.13, is the correct solution of the problem.

This method of determining marginal rates of return is, from a theoretical point of view, an ideal one. It suffers, however, from the very great practical difficulty that it can only be used when the algebraic equation satisfied by the inputs and outputs is at hand.

In the absence of this equation, the marginal rate of return at any point can be approximated by determining graphically the slope of the curve of total returns at this point. This may be done by placing a ruler tangent to the curve of total returns at the proper point and determining its rise during the selected interval of input. While this method is only a more detailed application of the graphical test suggested by Professor Edgeworth, it should be used with caution. A slight difference in the method of drawing the curve of total returns through the datum points will change its results considerably. It should, therefore, be used only when the datum points are well established and when they allow no choice in drawing the curve of total returns.

For the purpose of making visible at a glance the relative variation of the different kinds of returns discussed in this chapter, the following graph has been prepared, the datum points being taken from the above tables. In view of the fact that the size of average returns from marginal increments of input is partly dependent on the size of the marginal increments of input, no attempt was made to draw a curve through these points. Instead they have been marked by the little crosses.

FIG. 1. CORRELATION OF INPUT AND OUTPUT IN A HYPOTHETICAL PRODUCTIVE PROCESS



CHAPTER III

Diminishing Physical Returns in the Sources of Power for Agricultural Operations

Having considered the methods of determining the existence of diminishing marginal returns, it may be interesting to apply these methods in some simple cases of physical returns. Investigation shows that practically all phases of farming provide evidences of diminishing marginal physical returns. Among these are the sources of power for the conduct of agricultural operations, the application of fertilizers, seed and cultivation to the soil, and the transformation of food by farm animals.

Taking up the first of these, there are three sources of power which may be studied. They are, (1) human, (2) animal, and (3) mechanical. All show evidences of diminishing marginal physical returns. That the farmer's body, in the simple exercise of walking, is subject to the "inexorable law" was shown by Zuntz. In experiments performed some years ago he showed that the dynamic expenditure of energy[1] in walking rises more rapidly than the speed. Rearranging the results of these experiments as reported by Amar,[2] we get the following data:

---

[1] That is, the extra expenditure of energy involved in walking.

[2] Amar, Jules, *The Human Motor* (London, 1920), p. 373.

ECONOMY OF HUMAN BODY IN WALKING

Dynamic expenditure of energy (calories per hour per kg.)	*Speed (km. per hour)*	*Increase of speed per calory of increase of expenditure*
1.45	3.0	
1.72	3.6	2.22
2.35	4.8	1.90
3.48	6.0	1.06
5.33	7.2	.65
8.20	8.2	.35

It may be objected that this experiment and others to follow show increasing costs rather than diminishing returns because of the fact that the input is determined by the output. The table, in all probability, would have been more easily comprehensible if it had shown that increments of speed cause more than proportional increments of expenditure of energy. The two things, however, are really one and the same. All that is necessary for our purposes is that a certain input and a certain output be uniformly associated together.

The table shows that marginal physical returns diminish throughout the range of the data. It seems probable that if data had been collected for the speeds from zero to three kilometers per hour they would have shown a similar diminution of marginal returns.

If unburdened walking be subject to diminishing returns, it might be expected that carrying a load would be even more so. Experiments, however, show no great differences in the laws of energy expenditure affecting the two. Kolmer and Brezina, in an experiment reported by Amar,[1] discovered considerable increases in the consumption of energy per horizontal meter-kilogram (of body and load) in carrying various loads as the speed of walking was increased. Transforming their figures so as to get the marginal energy expenditures arising out of 600-meter increments in the speed of walking, it becomes possible to determine, as shown in the following table, the ratio of work done (in meter-kilograms of load) to energy expended as a result of these increments.

---

[1] Amar, Jules, *op. cit.*, p. 376.

Economy of Accelerating the Pace in Walking with Specified Loads. Ratio of Increase of Work Done (in meter-kilograms) to Increase of Energy Expended (in great calories) as a Result of 600-Meter Increments in Hourly Speed

Speed in meters per hour	*Load of 11 Kg.*	*Load of 21 Kg.*	*Load of 33 Kg.*	*Load of 43 Kg.*
3000	(293)	(472)	(661)	(702)
3600	282	435	672	682
4200	301	1180	501	503
4800	250	286	501	491
5400	138	281	323	270
6000	110	186	240	172
6600	88	120	158	

All of the above figures are based upon the results of tests which lasted two or three minutes only. Because of the well-known storage effect exhibited by living organisms, it is probable that longer tests would have shown different results. In particular, two or three figures in the table are out of line with the trend exhibited by the other figures and should probably be questioned.

The figures in parentheses have been included for comparative purposes only. They represent the total work done divided by the total energy expended at the speed of 3000 meters per hour. In view of the fact that a considerable part of this expenditure would take place independently of motion, these figures, to be comparable with the others, should be multiplied by at least two, and perhaps three or four.

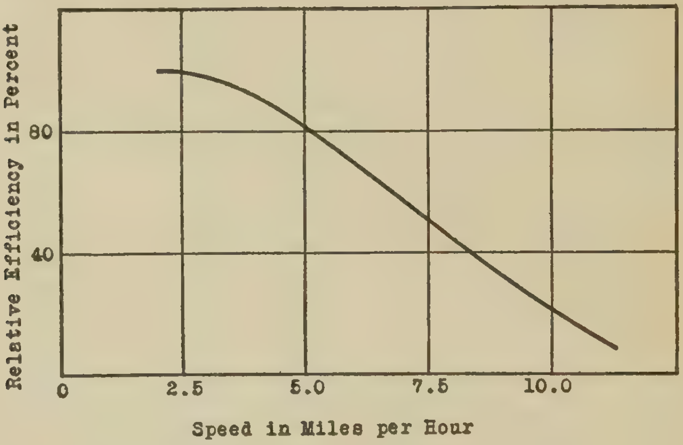
The table, if these exceptions and interpretations are correct, thus seems to show a general condition of diminishing marginal returns for all loads. But for the lighter burdens there is at moderate speeds a stage of constant, and perhaps even increasing, returns.

Not only do marginal returns diminish as speeds are increased, but the table contains clear indications that there is a decided limit to the economy obtainable by increasing the load. The burden of 43 kilograms is but slightly more economical than that of 33 kilograms at the lower speeds and less economical at the higher. Some fragmentary data given by Amar for a load of 53 kilograms show an economy markedly less than that for 43 kilograms. This seems to prove conclusively the wisdom of the practice of many explorers of limiting to sixty pounds the weight to be carried by any porter.

These facts are important because the human muscles have always been an indispensable source of power for agricultural operations, and until recently were most important in point of total power output. With the beginnings of civilization, however, man learned that the ox and horse, which had been originally domesticated for other purposes, could be trained to haul certain implements which he had invented for the purpose and could thus greatly increase his power of performing agricultural operations. In the civilized countries, therefore, the economy of the draft animal is equally important with that of man.

It might be expected that this economy would be substantially similar to that of man, but it is somewhat difficult to prove it, because the appliances used in measuring the efficiency of human muscles cannot be applied readily to those of animals. In spite of this difficulty, Fournier was able to perform experiments which showed that the maximum physical capacity of a draft horse to effect haulage declines rapidly as the speed is increased. For the particular type of horse with which he was working, he found the highest efficiency at speeds of two and two and one half miles an hour.[1] Putting this efficiency down as 100, the relative efficiency at other speeds is shown in Fig. 2.

Fig. 2. Relative Efficiency of the Draft Horse at Different Speeds



A more elaborate investigation of the economy of the draft animal was made by Zuntz. Working with a horse weighing 1100 pounds which carried no burden except 44 pounds of harness, he found a considerable increase in the consumption of nutrients per mile as the speed increased. From his results the following table has been computed:

Speed, miles per hour	*Net Nutrients Required, pounds per hour*	*Ratio of Increase of Speed to Increase of Consumption of Nutrients*
2.5	.335	(7.46)
3.5	.592	3.90
7.1	1.80	2.97

Parentheses have been placed about the first figure in the third column of the above table to indicate that it has a basis somewhat different from that of the others. It is, in fact, based not on the increase in the consumption of nutrients, but upon the total consumption at that speed. It is thus smaller than it would be if it were based on only the increase in consumption.

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[1] Thurston, *The Animal as a Prime Motor*, p. 52.

The table thus seems to indicate emphatically the existence of diminishing marginal returns, a condition logically in accord with that discovered above in the case of man.

In recent years a third source of power has been made available to the farmer. It is the internal combustion engine. Already it has made itself indispensable to certain types of farmers. As is well known, it is used in road haulage, in plowing, in the operation of threshers, ensilage cutters, etc. Great as its services have been, it has not freed the farmer from the limitations of diminishing returns. Increasing the speed of an engine up to a certain point causes rapidly increasing average returns. But increasing the speed beyond this point produces just as rapidly diminishing average returns. This is shown in a table reproduced by Amar.[1]

RELATION OF THE SPEED OF INTERNAL COMBUSTION ENGINES TO THEIR EFFICIENCY

Speed of Engine in Revolutions per minute	*Thermal Efficiency in per cent*
400	16.10
600	18.80
1000	19.30
1100	18.40
1225	15.40

It is equally futile to try to increase beyond a certain amount the total power output of an internal combustion engine by giving it more fuel. An investigation of the economy of small gasoline engines at approximately their rated speed by F. M. and E. A. White[2] shows that, with certain temporary exceptions, the marginal rate of power output diminishes as the gasoline input is increased. Of the twelve engines investigated, however, but four showed an uninterrupted diminution of marginal returns. Six of the others had a stage of increasing returns at about half their rated power output, while the other two, the largest of the lot, exhibited increasing returns at about their rated power output. This last phenomenon is probably to be regarded merely as evidence that the engines were improperly rated. In general the marginal power output diminished sharply as the rated power was approached, so sharply, in fact, that the Messrs. White summarized the results of their study in a graph which indicates that marginal returns diminish for all sizes of gasoline engine under 12 H.P. at all stages of power output.

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[1] Amar, *op. cit.*, p. 195.

[2] *Cf. Power*, vol. 38, pp. 299-301, Aug. 26, 1913.

This, however, is not true of average returns or efficiencies. Because of the large amount of internal friction to be overcome, about twenty percent of the maximum consumption of gasoline takes place before there is any power output at all. Additional gasoline supplied at this point leads to the production of power and thus causes average returns to increase. Beyond a certain point, however, the decline of marginal returns causes average returns also to diminish. This is illustrated in the following table in which the first two columns contain the results of one of the tests by the Messrs. White of an engine rated at 3 H.P., and the later columns have been computed from them.

These experiments with gasoline engines thus seem to indicate that in the internal combustion engine, as in the animate organism used for the production of power, diminishing marginal physical returns are to be regarded as normal, and stages of constant or even increasing returns as only temporary interruptions of a general trend. In both cases, likewise, because of heavy fixed expenditures of

Economy of a 3 Horsepower Gasoline Engine

Power Output in Brake H.P.	*Gas Consumption lbs. per H.P. Hr.*	*Total Cons. lbs. per Hr.*	*Average Ret. H.P. per lb.*	*Ratio of Increment of Power to Increment of Gas. Cons.*
0.73	1.74	1.27	.574	
1.47	1.15	1.69	.870	1.76
2.26	1.01	2.28	.990	1.34
2.50	0.99	2.48	1.01	1.23
3.26	1.17	3.81	.855	.57

energy, average returns rise up to a certain point, beyond which they follow, but more slowly, the fall of marginal returns.

CHAPTER IV

Diminishing Physical Returns in the Application of Fertilizers, Seed and Cultivation to the Soil

So prominent has been the part played in economic theory by the law of diminishing returns, that it comes somewhat as a surprise to discover that its physical workings in agriculture had been accidentally determined in some fertilizer experiments performed by Arthur Young fifty years before economists were aware of the existence of the law. "In the year 1771," Arthur Young tells us, "I marked out a rood of land into divisions and sowed them with oats. The variety of manures made use of in this experiment are marked as follows:[1]

Division	*Proportion per Acre*	*Produce per Acre*	
No. 1	40 cubical yards of farmyard compost, etc.	40 bushels	2½ pecks
No. 2	20 ditto	51	1
No. 3	10 ditto	45	0
No. 4	10 ditto	46	1
No. 5	10 loads of bones, each 40 bushels	63	1
No. 6	20 ditto	57	0
No. 7	200 bushels of lime	38	1¾
No. 8	40 yards of chalk	31	1
No. 9	No manure	30	2½
No. 10	80 yards of chalk	25	2½
No. 11	120 yards of chalk	27	2

N. B.—The season was remarkably dry, which circumstance certainly had a considerable effect on the different crops.

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[1] From *A Comparative View of Manures* by Arthur Young, printed by Dr. A. Hunter in his *Georgical Essays* (London, 1803). It seems probable that it was the publication of this essay in 1803 which made it possible for four economists to think almost simultaneously a few years later of the law of diminishing returns in agriculture, *cf. supra*, p. 9.

Rearranging the results of this experiment, as is done in the following table, we see clearly that we are here dealing with three experiments and not one.

ARTHUR YOUNG'S FERTILIZER EXPERIMENTS

Number of Plot	*Kind and Amount of Manure Applied*	*Yield of Oats*		*Marginal Yield*	
		bushels	*pecks*	*bushels*	*pecks*
9	None	30	2½		
3 & 4	10 cu. yd. compost	45	2½	15	0
2	20 ditto	51	1	5	2½
1	40 ditto	40	2½	–5	1¼ average
9	None	30	2½		
5	10 loads of bones	63	1	32	2½
6	20 ditto	57	0	–6	1
9	None	30	2½		
8	40 yards of chalk	31	1		2½
10	80 ditto	25	2½	–5	2½
11	120 ditto	27	2	1	3½

In each of the above experiments we notice, on inspection, that marginal physical returns not only did not increase, but diminished steadily, and in each instance became negative. In the last experiment, for instance, the application of 80 cubic yards of chalk to the soil injured it to such an extent that the yield of oats was five and a half bushels less than if no chalk at all had been applied. This agrees with the common observation that any plant nutrient may be applied to the soil in such quantities as to injure yields.

The dependability of these results is of course greatly lessened by the fact that insufficient care was taken to assure the uniformity of the plots and that the experiment lasted only one year. It is probable that the effects of the fertilizers would have been much more pronounced had the experiments continued several years longer. Experience shows that considerable time is required by the soil to accustom itself to a new regime. It is now known that this is due to the gradual nature of the changes in the quantity and quality of bacteria in the soil which result from a change in the system of fertilization and cropping.

Since 1771, the year of Arthur Young's experiments, similar investigations have been carried on in many places and on a large scale. As a result there are now available data on the subject far more detailed and accurate than his.

Probably the most thorough of these experiments are those which have been going on at Rothamsted, England, since 1843. One of the early experiments at that station was performed to find out the effect on wheat yields of various amounts of a mixed nitrogen fertilizer. From 1852 to 1864 inclusive it gave the following results:[1]

ROTHAMSTED EXPERIMENT ON THE EFFECT OF NITROGEN SALTS ON YIELDS OF WHEAT

Number of Plot	*Manures Applied per Acre*	*Total Yield of Wheat, bu.*	*Marginal Yield*	*Total Yield of Straw, cwt.*	*Marginal Yield*
5	Mineral Salts	18.3		16.6	
6	M. S. & 43 lbs. N.	28.6	10.3	27.1	10.5
7	M. S. & 86 lbs. N.	37.1	8.5	38.1	11.0
8	M. S. & 129 lbs. N.	39.0	1.9	42.7	4.6
16	M. S. & 172 lbs. N.	39.5	0.5	46.6	3.9

The nitrogen applied in this experiment was contained in a mixture of fixed proportions of ammonium nitrate and ammonium sulphate. The mineral salts were applied to all the plots in the same amounts year after year, and for our purposes may be left out of account.

What are the lessons as to diminishing physical returns which may be drawn from this experiment? In the first place, as in Arthur Young's experiment, there is no stage of increasing marginal yields of grain "up to a certain point". It is true that the marginal yields of straw show one stage of slightly increasing returns and in all cases fall off less rapidly than the marginal yields of wheat. This, however, does not invalidate the above principle, for straw is an inconsequential by-product of wheat production. It agrees well with the common observation that an over-fertile soil causes an over-development of stalks and leaves at the expense of grain and fruit.

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[1] Hall, *The Book of the Rothamsted Experiments* (London, 1919), p. 46.

Another experiment which has continued long enough to be dependable is one being conducted at the Pennsylvania Agricultural Experiment Station.[1] It was undertaken with a view to determining the effects of varying amounts of barnyard manure on crop yields in a four-year rotation of corn, oats, wheat and hay. The only possible means of adding these crops together for the purpose of determining total yields is that of value, and it will have to be used in this instance, though it may create a doubt as to whether the returns are physical.

Omitting the first twenty-five years of the experiment in order to make sure that the soil had become thoroughly accustomed to the experimental regime, the twenty-sixth to thirty-fifth years inclusive (1907-1916) gave the following results, on the basis of average values from 1901 to 1915:

PENNSYLVANIA EXPERIMENT ON THE EFFECT ON CROP YIELDS OF VARIOUS RATES OF APPLYING MANURE TO THE SOIL

Manure Applied tons per acre	*Value of Crops Produced*	*Ratio of Increment of Crop Value to Increment of Manure Applied*
0	$58.00	
6	114.79	9.47
8	117.22	1.22
10	127.58	5.18

If one were to judge by the figures in the column of marginal returns (that to the right), one would be compelled to say that marginal physical returns diminish up to a certain point and then increase. This paradoxical conclusion would of course be incorrect, for there is no reason to doubt that if the application of manure had been carried to still higher rates, sharply diminishing returns would have been encountered. All that this experiment really proves is that the regular diminution of marginal physical returns in the application of fertilizers to the soil is frequently interrupted, even at fairly intensive rates, by periods of increasing returns.

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[1] *Bulletin 146*, Pennsylvania State Agricultural Experiment Station, pp. 13, 27.

Another well-authenticated experiment which shows increasing returns at an advanced intensity of fertilization is one which has been going on at the Ohio Agricultural Experiment Station since 1895. It was undertaken for the purpose of determining the effect of various applications of barnyard manure on a potatoes-wheat-clover rotation. The plots are one-tenth acre in size, and of these several are not fertilized at all, one receives four tons per acre, another eight, and the last sixteen. In all cases the manure is applied to wheat only. The effects of these applications of fertilizer for the years 1906-1918, expressed in terms of the percentage by which the crop exceeded that of the unfertilized plots, were as follows:

Ohio Experiment on the Effect on the Yield of a Potato–Wheat–Clover Rotation of Various Rates of Applying Manure to the Soil

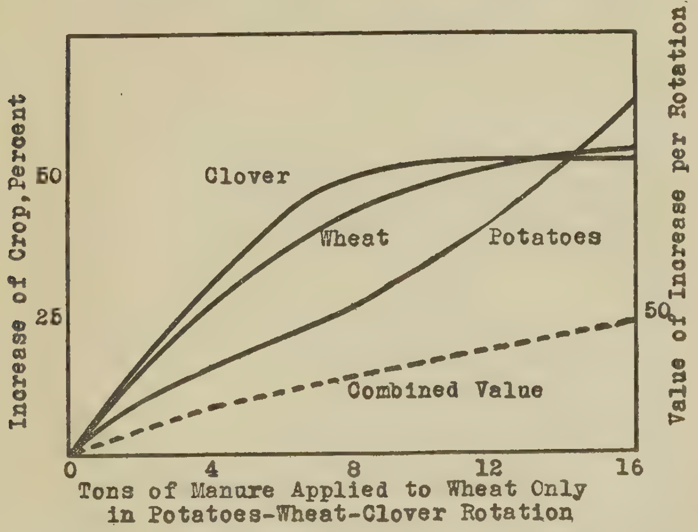
Number of plot	*Manure applied tons per acre*	*Increase of yield, per cent*			*Value of increase*	*Ratio of Increment of crop value to Increment of Manure*
		Potatoes	*Wheat*	*Clover*		
17	4	15.4	26.4	29.6	$16.91	4.23
18	8	26.2	42.9	49.4	27.41	2.63
32	16	62.6	54.4	52.3	46.94	2.88

Fig. 3 makes the results of this experiment visible at a glance. Because of the absence of datum points in the in-

[1] *Bulletin 336,* Ohio Agricultural Experiment Station, pp. 619-624.

terval between the applications of eight and sixteen tons of manure, however, the shapes of the curves in this interval should not be overemphasized. They are to be regarded as only approximately correct. With this caveat, the graph seems to bring out more clearly than the table several important facts. The increment from eight to sixteen tons of manure was slightly more effective in increasing crop value than that from four to eight. This increase of marginal returns was entirely due to a striking increase in the marginal yield of potatoes, both wheat and clover showing diminishing returns. This experiment thus confirms the results of the Pennsylvania experiment. In both instances a well-established stage of increasing returns occurred at a fairly advanced intensity of fertilization.

FIG. 3. YIELDS OF CLOVER, WHEAT AND POTATOES IN ROTATION AS AFFECTED BY VARIOUS RATES OF APPLYING BARNYARD MANURE



In each of these experiments it will be observed that a crop rotation rather than a single crop was used. Experience shows rather generally that the introduction of crop rotations has made it possible to cultivate the soil more intensively without encountering seriously diminishing returns.

Not only do mixed crops delay the diminution of returns, but mixed fertilizers seem to have the same effect. Judging by the results of some Ohio experiments,[1] combinations of certain fertilizers increase yields of a potato-wheat-clover rotation by an amount usually greater than the sum of the increments of yield secured when the fertilizers are used separately.

INCREASING RETURNS FROM CERTAIN COMBINATIONS OF FERTILIZERS AS SHOWN BY AN OHIO EXPERIMENT WITH A POTATO-WHEAT-CLOVER ROTATION

Plot Number	*Fertilizer Used*	*Value of Increased Yield per Rotation, 1909-1923*
2	Acid Phosphate, 320 lbs. per acre	$10.51
3	Muriate of Potash, 200 lbs. per acre	13.84
5	Nitrate of Soda, 200 lbs., Dried Blood, 50 lbs.	7.65
	2 and 5 used separately	18.16
6	2 and 5 used together	21.29
	2 and 3 used separately	24.35
8	2 and 3 used together	34.90
	3 and 5 used separately	21.49
9	3 and 5 used together	26.25
	2 and 3 and 5 used separately	32.00
11	2 and 3 and 5 used together	39.63

The reliability of these results is greatly increased by the fact that the first fifteen years of the experiment have been excluded. It is no doubt true that a great deal depends on the kinds of fertilizers used together. Assuming, however, the choice of congruous fertilizers, there seems to be no way of delaying the diminution of marginal returns better than the device of using other fertilizers.

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[1] *Bulletin 381*, Ohio Agricultural Experiment Station, p. 332.

One fact which has not yet been sufficiently emphasized is that any plant nutrient can easily be applied to the soil in such quantities as to cause the total crop yield to decline. The one-year experiments of Arthur Young ended in this result in every instance, but with the exception of experiments with such cheap nutrients as lime, modern agricultural experimenters have rarely carried the application of fertilizers to this extent. If water be considered a nutrient, however, we have an example from an experiment performed at the Utah Agricultural Experiment Station of the damage which may be done by the application of too much irrigation water. The average effect on potato yields of the application of various amounts of irrigation water is shown as follows:[1]

THE EFFECT ON YIELDS OF POTATOES OF VARIOUS APPLICATIONS OF IRRIGATION WATER

Water Applied Inches per Week	*Yield of Potatoes In Bushels*	*Ratio of Increase of Crop to Increase of Water*
0	153	
1	337	184
2½	301	–24
5	191	–44
7½	141	–20

From the column of total returns we may surmise that the point of maximum yield will lie in the vicinity of the application of 1¼ to 1½ inches of water weekly. Whatever the exact point, it is undeniable that every application of water over 2½ inches weekly has an injurious effect on crop yields. It is obvious that to get maximum yields the plant nutrients must be concentrated in the soil in just the right proportions to meet the needs of the plant.

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[1] *Bulletin 157*, Utah Agricultural Experiment Station.

The fact, illustrated by this table, that any plant nutrient can be applied in such abundance that it causes a decrease in crop yields is of particular importance in view of the fact that a recent book on diminishing returns in agriculture[1] is largely devoted to the task of demonstrating the existence of a law of diminishing physical returns in agriculture which makes no provision for marginal returns becoming negative. This law, called "the law of the diminishing increment" is based on the assumption that the returns to successive unit increases in the rate of applying fertilizer (or any other input) to the soil "tend to constitute the terms of a decreasing geometric series".[2]

It is hard to see how this assumption can be reconciled to more than a small proportion of the results of agricultural experiments. The data given in this chapter show the irregular variation of marginal returns. Several instances of the occurrence of increasing returns in the midst of diminishing returns have been noticed, and if this latest table is representative, as it is believed to be, marginal returns in all instances may become negative. Both of these facts seem to show the non-existence of the law of the diminishing increment, or in fact, of any such simple law.

Aside from plant nutrients, there is but one thing the farmer must apply to the soil to secure a crop which remains to be considered. It is the seed. Experiments show that the same law applies to the application of seed as has been observed in the case of fertilizers. The Ohio Agricultural Experiment Station, for instance, has undertaken an investigation of the effects on crop yields of various rates of sowing wheat.[3] The average of seventeen years of this experiment shows the following results:

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[1] W. J. Spillman and Emil Lang, *The Law of Diminishing Returns* (Yonkers, 1924).

[2] *Op. cit.*, p. 1.

[3] *Monthly Bulletin*, Aug., 1916.

THE EFFECT ON THE YIELD OF WHEAT OF VARIOUS RATES OF SEEDING

Pecks of Seed Used per Acre	*Total Yield per Acre, bu.*	*Marginal Yield bushels*	*Marginal Yield to 2 peck dose*
3	24.24		
4	26.18	1.94	3.88 av.
5	26.98	.80	
6	28.19	1.21	2.01
7	28.06	−.13	
8	28.96	.90	.77
9	29.06	.10	
10	29.06	.00	.10

It will be observed that the column showing the marginal yields attributable to one peck increments in the rate of seeding contains extreme irregularities. These are probably due partly to the smallness of the dose and partly to the inherent differences of the plots used. The use of larger doses usually lessens greatly such irregularities and in this instance the adoption of a two-peck marginal unit wipes them out completely and brings out clearly the lessons of the experiment. These are first that increasing application of seed to the soil is subject to diminishing returns, and second that the application of more than eight pecks per acre does not produce sufficient increment in yield to repay the extra seed used.

Another Ohio experiment, on the rate of planting corn, shows similar results. It concerns the proper number of plants per hill, the number of hills being kept constant at 3555 per acre throughout the experiment. Average yields for 1904-1914 were as follows:[1]

THE EFFECT ON YIELDS OF CORN OF THE NUMBER OF PLANTS PER HILL

Plants per Hill	*Yield of Corn Bushels per Acre*	*Yield Due to Marginal Plant*
1	31.7	31.7
2	50.8	19.1
3	60.8	10.0
4	64.9	4.1
5	63.0	−1.9

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[1] *Bulletin 282,* Ohio Agr. Exp. Sta.

An even more striking instance of the injury wrought by over-seeding is afforded by still another Ohio experiment.[1]

THE EFFECT ON ALFALFA YIELDS OF THE AMOUNT OF SEED SOWN PER ACRE

Pounds of Alfalfa Seed Sown per Acre	*Yield of Alfalfa Pounds per Acre*	*Yield Due to Marginal Five Pounds of Seed*
5	7863	7863
10	8650	787
15	8680	30
20	8557	–123
25	7875	–682

The lesson taught by this table is too clear to require comment.

There remains for treatment in this chapter perhaps the only other kind of agricultural operation, aside from the application of fertilizers, irrigation water and seed to the soil, which can be reduced to definite quantities of physical input. It is the operation of tillage. It is of particular interest in an essay dealing with diminishing physical returns in agriculture because it has in the past been the most frequently used of all the supposed "illustrations" of diminishing returns.

A typical, and probably the original, statement of this supposed illustration is found in the famous note written by the French economist Turgot on the edge of a prize essay submitted to him for judgment. The note, in part, reads:

> Seed thrown on a soil naturally fertile but totally unprepared would be an advance almost entirely lost. If it were once tilled the produce will be greater; tilling it a second, a third time, might not merely double and triple but quadruple and decuple the produce, which will thus augment in much larger proportion than the advances increase, and that up to a certain point, at which the produce will be as great as possible compared with

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[1] *Ohio Agr. Exp. Sta. Report*, 1907-8.

the advances. Past this point, if the advances be still increased, the produce will still increase, but less and always less and less until the fecundity of the earth being exhausted, and art being unable to add anything further, an addition to the advances will add nothing whatever to the produce.[1]

A little investigation will show that the ideas contained in this note were already old when Turgot gave them expression. Only a decade or so earlier Jethro Tull, an English pioneer in scientific agriculture, built up a whole philosophy to support the practice of multiple plowings. In *Horse Hoeing Husbandry* (1751) he laid down his theory that plants in growing draw in through their roots extremely minute particles of soil, and on this ground argued for his pet scheme of thoroughly pulverizing the soil. After many allusions to the profitableness of his plan he states on page 41: "The first and second plowings with common ploughs scarce deserve the name of tillage. The third and fourth and every subsequent plowing may be of more benefit and less expense than any of the preceding ones. But the last plowings may be more advantageously performed by way of hoeing."

Even Tull can hardly be said to have been original in this theory. He was merely building up a plausible argument for a practice which was thoroughly familiar to most of his readers. For plowing was the great work of the Middle Ages. Under the open-field system the fallow field was plowed twice during the summer months. It thus worked out that in the three-field system the land was plowed twice for every time it was cropped, while under the two-field system it was plowed three times.

Still more numerous plowings formed the basis of the supposed advantages of one of the famous agricultural schemes of the late Middle Ages. In the sixteenth century we find a certain Venetian, Sr. Tarello de Leonato by name, claiming a royalty on all lands using his scheme for increasing production with no increase in agricultural work. The essence of the scheme is contained in the proposal "that the labor which till this time has been bestowed on two parts of land for wheat (each of which has been plowed four times) shall from henceforth be given to one only; so that it may be plowed eight times, including the seed furrow." [1]

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[1] Quoted from E. Cannan, *Production and Distribution*, p. 148.

Even the Middle Ages did not originate the scheme of multiple plowings, for we find Columella, the famous classical writer on agriculture, saying (Lib. IV, Cap. V), "Numerus autem vertendi soli (bidentibus) definiendus non est, cum quanto crebrior sit, plus prodesse fossionem conveniat. Sit impensarum ratio modum postulat." Which may be translated, "But the number of times the soil should be turned with two-tined cultivators cannot be definitely laid down, since the more frequent it is the more the soil will produce. It will be fixed by the amount of outlay."

Sharply divergent from these writers in the matter of repeated plowings is modern agricultural practice. Adopted because of its known ability to produce profits, this practice allows but a very minimum of plowing and cultivation.

Which is right in the matter? If the agricultural experiment stations are to be given the deciding vote, it will undoubtedly be cast in favor of modern farming practice. So firmly are they convinced of the precipitous diminution of returns from repeated tillings that they have apparently thought it not worth while to spend money in elaborate investigations of the matter. Such experiments as have been undertaken have been so decisive that they have been quickly discontinued. This is true, for instance, of the one-year experiment performed by the Arkansas Agricultural Experiment Station in 1898. The results were:[1]

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[1] De Leonato, *Ricordo d'Agricultura* (Mantua, 1577).

The Effect of Repeated Tillage on the Yield of Wheat

Kind and Amount of Tillage	*Total Yield Bushels per Acre*	*Yield Due to Marginal*	
		Plowing	*Harrowing*
Plowed Once	16	12 (?)	
Plowed Once and Harrowed Once	18½		2½
Plowed Twice and Harrowed Once	21⅔	3 1/6	
Plowed Twice and Harrowed Twice	23¼		1 7/12

The figure for the marginal yield of the first plowing was based on the assumption that a yield of four bushels per acre could have been obtained without any plowing at all. Whatever the correct figure may be, it is clear that returns from repeated plowings or harrowings fall off sharply.

In recent years, great things have been claimed for deep plowing and dynamiting, two new varieties of intensive plowing. Several investigations of these practices, however, have shown that the increased yields secured in this way, if any, were not worth the extra cost.

A similar conclusion must be drawn in regard to the intensive cultivation of growing corn. The following data, resulting from investigations conducted by the Ohio and Kansas agricultural experiment stations, show that all cultivations beyond two or three are disadvantageous.

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[1] These data were quoted by Marshall in a foot note as an illustration of the idea of marginal return. They thus apparently enjoy the proud position of being the first, and, until recently, the only, actual data ever quoted in a discussion of diminishing returns. For Marshall's reference *cf. Principles of Economics* (London, 1910), p. 155.

THE EFFECT ON YIELDS OF REPEATED CULTIVATIONS OF GROWING CORN

Number of Cultivations	*Ohio Exp. Station Yields*[1] *Total*	*Marginal*	*Kansas Exp. Station Yields*[2] *Total*	*Marginal*
1			37.62	
2			47.42	9.80
3	72.57		43.77	−3.65
4	71.71	−0.86	48.94	5.17
5	67.50	−4.21	48.27	−0.67
6	70.27	2.77	49.34	1.07
7	69.92	−0.35		

These experiments show the contradictions to be expected in experiments of short duration, small increments of input and uncontrolled plots. They bring out clearly, none the less, the fact that there is no advantage in numerous cultivations. In both instances, cultivations beyond two or three were either injurious, or produced no additional yield worth the extra expense.

The conclusion of the whole matter seems to be that no form of agricultural operation yields such sharply diminishing returns as tillage. It remains a mystery how the belief that it yields increasing returns up to an advanced point could have survived in theory and practice so many centuries.

In summing up the evidence presented thus far in this chapter several things stand out clearly. The results of the well-established and representative experiments here recorded: (1) provide no evidence of the general existence of increasing marginal physical returns "up to a certain point" for any form of agricultural input, (2) show, in two striking instances, the possibility of increasing returns at an advanced rate in the application of fertilizers, (3) indicate that no form of agricultural input yields such sharply diminishing marginal physical returns as tillage, and (4) suggest that any form of agricultural input may be carried to such an intensity as to cause total returns to fall off.

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[1] Report of Ohio Agricultural Experiment Station for 1888, pp. 86, 87.

[2] Bulletin 64 Kansas Agricultural Experiment Station, p. 86.

In connection with the first of these points it is pertinent to inquire whether the flat statement may be fairly made that there is no evidence of the general existence of an initial stage of increasing marginal physical returns in agriculture. The author's investigation of the matter would support such a conclusion. It cannot be denied that instances of initial increasing returns are occasionally found, but the number of such instances seems to be no greater than, if as great as, the number of instances of increasing returns at a fairly advanced intensity of input.

The suggestion has sometimes been made that if the initial increments of input were made much smaller than those which have been generally tried by the experiment stations, the results might be different. In the absence of empirical data bearing on this matter, resort must be had to the opinions of soil theorists. Judging by the various laws of soil productivity worked out by a distinguished list of investigators mentioned by Dr. Lang,[1] the chance of the existence of such a stage of increasing marginal physical returns is not great.

The earlier experimenters, including Liebig, Adolph Mayer, Wollny and Paul Wagner, maintained that as long as a growth factor was present in less than the optimum amount its increase would lead to proportional increments in returns. What is regarded as a much closer approximation to the facts of soil productivity is the logarithmic law worked out by the present leader of soil theorists in Germany, Dr. E. A. Mitscherlich. According to this law, marginal physical returns arising out of the increased application of a given fertilizer diminish in such a way that the logarithm of the amount by which the yield obtained by the use of any amount of the fertilizer falls short of the maximum yield obtainable by its use is a rectilinear function. Whatever the relative merits of the proportional principle and this logarithmic law, it will be observed that neither permits the existence of an initial stage of increasing returns.

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[1] Spillman and Lang, *The Law of Diminishing Returns* (Yonkers, 1924), pp. 89-162.

Some color is lent to the possibility of such a stage, however, by the work of the Göttingen mathematician, Baule, who has attempted to adapt the Mitscherlich formula to the simultaneous increase of two or more vegetative factors. Assuming that the yields obtainable in this way increase as the product of the effects of the factors when used separately, he derives a formula which allows of increasing marginal physical returns to an extent depending on the number of factors which are being simultaneously increased. Dr. Lang refers to this formulation of the Mitscherlich law as " completely substantiated ", although he does not quote the experimental results which substantiate it. In fact he warns his readers more than once that the conditions under which the Baule formulation applies are not common. Its main limitation seems to be that it is valid only for growth conditions that do not mutually affect each other.[1] Nor does it seem to have been determined just what growth conditions there are that do not mutually affect each other. It is not even certain that more than two independent growth conditions can be actually controlled in commercial agriculture. For these reasons Dr. Lang seems inclined to wait till the Baule formulation is tested in a purely practical way before drawing practical conclusions from it.

The general absence of any evidence for a sigmoid curve of total returns is commented upon by Professor Spillman in his chapter introducing Dr. Lang's discussion,[2] and explanations of it given which only serve to emphasize the unproved character of the Baule formulation. Professor Spillman's own formulation of the law of the soil provides that marginal returns to successive equal doses of fertilizers diminish in geometric ratio[1]

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[1] Spillman and Lang, *op. cit.*, p. 148, note.

[2] *Op. cit.*, pp. 58-59.

The opinions of certain distinguished soil theorists thus seem to be at variance with the belief expressed by several economists that normally there is an initial stage of increasing marginal physical returns in agriculture. In fairness to the latter, therefore, the other side of the question should be presented. To the writer, at least, the evidence of initial increasing returns provided by these economists seems to be entirely circumstantial in character.

The farmers of any district, it is said, commonly find it profitable to carry their application of fertilizers only up to a certain point. From this the conclusion is drawn that returns must increase up to this point and diminish beyond it. But what kind of returns? The argument itself makes it clear that it is aggregate profits that increase up to a certain point, and not returns of any kind, to say nothing of marginal physical returns. All that the above situation proves in regard to marginal physical returns is that their value is in excess of the cost of the corresponding increments of input up to a certain point. As far as argument is concerned, they may behave in any possible way up to this point. Experiments seem to show that they diminish generally from the beginning. The most profitable increments of input are, therefore, in most instances the initial ones. If this contention is correct, the belief in an initial stage of increasing marginal physical returns as a general characteristic of agriculture is to be ascribed to a failure to distinguish between marginal physical returns and total money profits.

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[1] *Op. cit.*, p. iii.

CHAPTER V

DIMINISHING PHYSICAL RETURNS IN FOOD TRANSFORMATION BY FARM ANIMALS

THUS far we have considered the various forms of physical diminishing returns to be observed in the farmer's sources of power and in his utilization of the soil. There remain to be considered the varieties of the phenomenon which occur in the process by which farm animals transform foods largely unavailable to man into the proteins and fats which he can digest.

The digestive and metabolic mechanism of food animals is an indispensable means of turning hay, fodder and grain into milk, meat and eggs. While, under the influence of selective breeding, the efficiency of this mechanism is constantly improving, it is none the less, whether efficient or inefficient, subject to diminishing physical returns.

That this is true of the steer was shown several years ago by an investigation at the Illinois Agricultural Experiment Station.[1] In this experiment sixteen two-year-old, high-grade Holstein steers were divided into four groups of four each and fed a standard ration the contents of which were the same for all groups. One group received an amount of the ration computed to be barely sufficient to enable it to hold its own in weight. Another group received an amount about equal to all it could eat, and the other two groups received amounts one-third and two-thirds of the way between these extremes. Tests were made of the economy of gain for several periods of five or six weeks each, extending in all over thirty-seven weeks. As the conditions of the experiment were changed in the last period of feeding, it has been eliminated from the results here given.

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[1] Bulletin 197, Illinois Agricultural Experiment Station, p. 588.

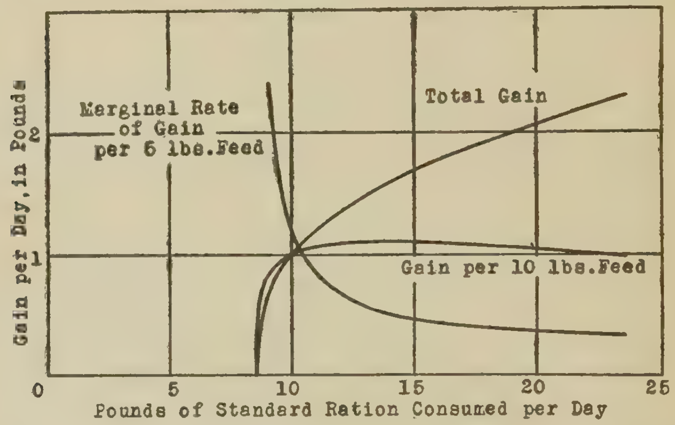
Economy of Various Rates of Feeding a Standard Ration to Two-Year-Old Holstein Steers

Average Daily Input of Feed in Pounds	*Average Daily Gain in Pounds*	*Gain per Pound of Feed*	*Average Gain per Pound of Marginal Increment in Daily Feed Input*
9.03	.553	.062	.062
14.21	1.602	.1125	.203
19.37	2.05	.106	.0868
23.13	2.27	.098	.0585

It will be observed that the so-called maintenance group gained slightly on the ration supplied to it. As a result of this gain it was computed that a true maintenance ration would have supplied only about eight and one-half pounds of the ration a day. This point has accordingly been plotted along with the experimentally determined points in the following graph, Fig. 4, which seems to bring out the real lessons of the experiment more clearly than the table. The curves of total and average returns pass through the datum points given in the table.

The curve of marginal returns was obtained by determining at appropriate points the slope of the curve of total returns. As the results of this method depend to a considerable extent on the way in which the curve of total returns is drawn, it was deemed best, in spite of the apparent lack of liberty in drawing permitted by the above data, to err, if at all, on the side of conservatism. The curve was accordingly drawn to begin somewhat lower and end somewhat higher than the slope of the curve of total returns would permit. The diminution of marginal returns which it indicates, though much greater than one would suppose from an inspection of the column of marginal returns in the above table, is probably less than that which actually occurred.

FIG. 4. ECONOMY OF VARIOUS RATES OF FEEDING A STANDARD RATION TO TWO-YEAR-OLD HOLSTEIN STEERS



In sharp contrast with the rapid diminution of marginal returns is the behavior of average returns. As indicated by the curve showing " Gain per 10 lbs. Feed ", they exhibit a remarkable uniformity in the interval between 10 and 23 pounds of ration consumed per day. It was no doubt this uniformity, together with the confusion of results arising out of the change of the conditions of the experiment in the last period, that led the authors of the report on the experiment to make the statement that "Taking the entire thirty-seven weeks of the experiment into consideration, there seems no reason to conclude that the amount of feed consumed had any effect on the economy of gains." The column of marginal returns in the table, to say nothing of the curve of marginal returns in the graph, makes it hard indeed to agree with this statement.

Not only does the economy of the meat animal decline as the daily rate of feeding is increased, but there is also a secular fall in economy throughout the life of the animal. This is shown in the following table, the data for which were computed from data in Bulletin 34 of the Kansas Agricultural Experiment Station.

SECULAR CHANGES IN THE ECONOMY OF GAIN IN STEERS

	Pounds of Grain for 100 lbs. Gain	*Pounds Gained per 100 lbs. Grain*
Up to 56 days, the steers required ...	730	13.7
" " 84 " " " "	807	12.4
" " 112 " " " "	840	11.9
" " 140 " " " "	901	11.1
" " 168 " " " "	927	10.8
" " 182 " " " "	1000	10.0

The column to the right indicates the average rate of gain for the whole life of the steers up to the age indicated. It therefore shows average returns. As always in such instances, the marginal returns, if in such form that they could be computed, would decline much more rapidly than the figures for average returns. The column shows clearly, even as it is, that there is a secular diminution of returns in the transformation of grain into beef by the metabolic mechanism of steers.

That the same thing is true of swine has been shown by many experiments. Among others, an investigation made by the Ohio Agricultural Experiment Station, reported on page 549 of its Bulletin 335, showed that the first hundred pounds gained by hogs cost only 2.89 pounds of feed per pound of gain, the next hundred cost 3.85 pounds of feed per pound, the third hundred cost 4.45 pounds per pound, the fourth 4.49 pounds, while the fifth hundred pounds gained cost 5.34 pounds of feed per pound of gain, almost twice the cost of the first hundred pounds. In other words, the efficiency of the hog in converting feed into flesh declined nearly 50 per cent as the weight increased from 3 to 500 pounds.

This secular decline in the economy with which the animal mechanism transforms grain and fodder into flesh had long since been discovered empirically by farmers and explains why they commonly market their cattle and swine before they have attained two-thirds of the weight which they are physically capable of attaining. It is also interesting as a basic difference between the animate and the inanimate mechanism. No variety of machine shows a secular change in economy except such as is due to the wearing out of its parts.

Another variety of food transformation of great importance for humanity is that performed by the dairy cow. As might be expected, this shows increasing average physical returns up to a certain point, followed by diminishing returns. This can be demonstrated by either experimental or statistical methods. The latter were recently used by the Cornell University Agrictultural Experiment Station in a study from which the following conclusions were drawn:

> Low production, either because of poor cows or scant feeding, usually requires more feed per unit of product than does higher production. Beyond a certain point, however, each additional pound of product requires more and more feed until the limit of the capacity of the cow to take feed is reached. Hence, highest yields require more feed per unit of product than do medium good yields. Except in the making of advanced registry records, rarely does it pay to force cows to the limit of their capacity.
>
> In the group of herds that produced less than 4500 pounds of milk, with an average of 4063 pounds, 100 pounds of milk were produced for each dollar's worth of feed except pasture; in the next group, with an average production of 4961 pounds,

this figure was 106 pounds; with an average of 5916 pounds, for cows in the next group, it was 111 pounds; in the group including cows of the highest production, averaging 7136 pounds, only 105 pounds of milk were produced for each dollar's worth of barn feed.[1]

In this, as in many other instances of the use of the statistical method, it is by no means clear that the things being compared were identical in all respects other than the one under consideration. To be explicit, there is no proof that the low-yielding and high-yielding herds were substantially the same in breed and age, and that they received the same amount of pasturage, etc. A strong presumption, however, is created that the conclusions as outlined are correct. Up to a certain point increments in the rate of feeding milk cattle seem to be rewarded by rising average returns. What does this indicate regarding marginal returns? It is not easy to say. The recently considered experiment relating to the fattening of beef cattle provided an instance of simultaneously rising average returns and sharply falling marginal returns. The same causative factor, a high internal energy expenditure, is present in this instance. If it be assumed that the above figures represent the results of as many different rates of feeding a given herd, a simple computation shows that marginal returns are approximately constant up to the third rate of feeding. Beyond that point marginal returns fall sharply. It is not improbable, therefore, that a fuller testing of this matter will reveal the same general tendency toward a diminution of marginal returns that has been observed in other methods of utilizing the animal mechanism.

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[1] Bulletin 409 Cornell Univ. Agr. Exp. Sta. "An Economic Study of Dairying on 149 Farms in Broome County, New York" pp. 390-1.

CHAPTER VI

Anticlinal Profits in Agricultural Enterprise

The self-sufficient farmer, if there be any such in this day and age, is directly affected by the phenomena of diminishing marginal physical returns which have just been considered. The typical modern farmer, however, is producing crops for the purpose of securing profits, and becomes interested in these phenomena only when they have been translated into money terms.

Fortunately this is easy to do. Any of the tables or curves given in the last three chapters can be translated into money terms by simply multiplying the figures of input by the cost of a unit of input and figures of output by the value of a unit of output. When this has been done and the results plotted it is discovered that the dimensions and the slopes, of the curves have been changed, but that otherwise their shapes have been unmodified.

The point of most profitable input can be found from the new curves by determining where the slope of the curve of total returns falls to 45 degrees, or where the curve of marginal money returns falls below the line whose ordinates are one. This method, however, is more laborious and probably less accurate than those described in Chapter II. The chief value of the construction of curves of money returns is that it makes it easy to visualize the variation of profits, and its causes, in the intensification of any of the productive processes of agriculture. Such curves make it clear, for instance, why the curve of profits rises up to a certain point beyond which it falls steadily, all the while that total money returns are increasing steadily and marginal money returns falling just as steadily.

It is vital to understand at this point why the curve of profits must always have this rising and falling shape (which will here be called *anticlinal* after the geological strata of the same shape). The reason is that sooner or later the curve of marginal money returns must cross and fall below the curve of marginal costs, and at this point the curve of profits must reach its highest point. Any smaller amount of input would produce a smaller amount of profit because certain profitable inputs would be missed. Any larger amount of input would likewise produce a smaller amount of profit, but the reason in this instance is that certain unprofitable inputs would be included and would thus cut down the total profits.

All of this argument relates to the money returns and profits to be derived by increasing any of the kinds of physical input which have been considered in the previous chapters. The purpose of this chapter, however, is to deal mainly with the factors which affect the profits of the agricultural operation as a whole. In dealing with this larger question we are at once brought face to face with the fact that there are certain very important costs in agriculture which have nothing to do with increased physical input. These are the fixed or overhead costs.

The nature of these costs may be made clear by an actual example. The following data relate to the cost per acre of producing wheat in North Dakota in 1923. They are averages of records kept on 122 scattered farms under the supervision of the Farm Management Department of the North Dakota Agricultural College.[1]

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[1] North Dakota Agricultural College, *Cost of Production of Wheat for 1923* (mimeographed report, Aug. 15, 1923).

ITEMS OF COST IN THE PRODUCTION OF WHEAT IN 1923 ON 122 NORTH DAKOTA FARMS

	Average Costs per Acre
Man Labor (including board)	$1.51
Horse Labor	1.21
Seed	1.48
Manure	.47
Twine	.22
Threshing	1.31
Tractor	.43
Automobile	.19
Machinery	.84
Miscellaneous	.99
Management	.52
Use of Land	3.06
Total	12.23

Which of these costs are fixed costs? In other words, which costs are independent of the intensity of cultivation? The only absolutely fixed cost in the list seems to be the charge for the use of land. However, assuming that the land is to be sown to wheat, the expenditures for plowing and seeding and two or three others are for the most part to be regarded as overhead. Let us assume that the fixed elements in these costs total six dollars per acre and that the rest of the costs are variable, reaching the figure of $6.23 when the yield is eight bushels per acre, and, on account of the fact of diminishing marginal physical returns, rising more rapidly than yield. Let us assume also complete continuity in the variation of the variable costs. We would then get approximately the following distribution of costs per acre.

Assumed Distribution of Costs per Bushel of North Dakota Wheat in 1923 for Various Yields

Yield, Bushels per Acre	*Fixed Costs*	*Variable Costs*	*Total Costs*
1	$6.00	$0.52	$6.52
2	3.00	.55	3.55
4	1.50	.60	2.10
8	.75	.78	1.53
12	.50	1.00	1.50
16	.38	1.30	1.68

This table makes it clear that if the distribution and variation of costs are as assumed, the cost of wheat per bushel will fall till a yield of about 10 bushels per acre is reached, and that beyond this yield costs per bushel will rise because variable costs rise more rapidly than fixed costs fall. However, it is not usually the object of the farmer to produce the greatest profit per bushel. His interest is to get the greatest aggregate profit for himself, and, assuming for the time being, that he has a fixed area of land to deal with, this is equivalent to getting the greatest profit per acre. The above figures will become more significant, therefore, when reduced to a per-acre basis.

This is done in the following table, in which are given the costs, total returns, average returns, marginal returns and profits per acre on the above lands, assuming wheat to bring $1.60 per bushel.

Assumed per Acre Costs, Money Returns and Profits on North Dakota Wheat Lands in 1923 for Various Yields, Assuming Wheat to be Worth $1.60 per Bu.

Yield, bu. per Acre	*Cost per Acre*	*Total Money Return per Acre*	*Average Money Return*	*Marginal Money Return*	*Profit*
1	$6.52	$1.60	$0.25		–$4.92
2	7.10	3.20	.45	$2.76	–3.90
4	8.40	6.40	.76	2.46	–2.00
8	12.24	12.80	1.05	1.67	.56
12	18.00	19.20	1.07	1.11	1.20
16	26.88	25.60	.95	.73	–1.28

The figures in the second column have been secured by multiplying the total costs per bushel for various yields as shown in the fourth column of the preceding table by the appropriate yields as shown in the first column. Average money returns were derived, as might be expected, by dividing total returns by total costs. The column of marginal money returns shows the average money returns for the marginal increments in cost. The figures in it were secured by dividing the increment in return by the increment in cost. The figures in the column of profit represent the total money returns less the total costs.

An examination of the trend of the figures in the last four columns shows that total money returns rise steadily, marginal money returns fall steadily, while both average money returns and profits rise and fall. Average returns apparently reach their highest point at a yield of about 10 bushels per acre, exactly the same point as that at which total costs per bushel reached their lowest point. Profits have the distinction of being negative most of the time but reach their highest positive figure apparently at a yield of about 12 bushels per acre. At least it would seem so from the fact that the increase in yield from 8 to 12 bushels was profitable *as a whole* by a safe margin.

The influence of the fixed costs is seen clearly in the column of average returns. The very heavy overhead expenditure involved in renting, plowing, seeding, etc., an acre of land makes a yield of one bushel per acre extremely costly. Conversely the average return for the money spent is very low, only one quarter, in fact. As more bushels are raised these overhead costs become spread over more bushels of crop and as a result average returns rise. Beyond a yield of 12 bushels per acre, however, this dilution of the overhead costs is more than counterbalanced by the rise of the variable costs, as we have seen, and average returns fall.

It is quite clear, therefore, that the initial rise of average returns is due to overhead costs, while the final fall is due to diminishing physical returns.

In this connection it is interesting to revert to the statement occurring in many books on economics that in agriculture returns rise up to a certain point beyond which diminishing returns set in. Because of the failure to differentiate the various kinds of returns it has never been made clear whether the kind of returns referred to in the definition is total, average or marginal. Some economists have supposed that their statement is applicable to physical returns and that average returns are intended as the measure. It seems probable, however, that this is a misapplication of the definition. The argument which establishes the truth of the definition is drawn entirely from agricultural enterprise.

This argument is to the effect that returns must rise and then fall because there is a more or less definite intensity of cultivation in each district of the country. This uniformity proves, it is said, either that farmers have discovered that returns rise up to this intensity and fall beyond it, or else that the process of natural selection which operates in the economic, as well as in the biological world has eliminated by means of low profits or even bankruptcy those farmers who departed too far from the optimum intensity of cultivation. Without debating the soundness of this argument, it is clear that it relates to the whole operation of farming and not to the restricted part measurable by experiment.

From the writer's point of view, therefore, the common statement of the law of diminishing returns in agriculture is applicable to agricultural enterprise, and the kind of returns referred to must be average, or else not returns at all, but profits. We are restricted to these two because the above table shows that they alone have curves of the anticlinal shape demanded by the statement.

Which of the two is it? We can only judge by the statements and arguments of economists. Many of them say that it is to the interest of farmers to carry their operation beyond the point of maximum returns per acre. These economists are obviously thinking of average returns. Others state that farmers should keep their cultivation at the point of maximum returns. They are obviously thinking not of returns at all, but profits.[1]

It is perhaps unnecessary to make a choice between the two. What is vastly more important is to make clear at all times whether it is total returns, average returns, or profits which are under consideration. The anticlinal shape of the curves of both average returns and profits is highly significant. And the most significant difference between the two is that the former reaches its maximum considerably before the latter.

If a choice *must* be made, preference should probably be given profits, since it is the governing factor in agricultural and every other kind of business enterprise. Hence the title of this chapter. Whatever the correct interpretation of the statement of economists should be, it is clear that the principle of anticlinal profits in the intensification of the cultivation of a given area of land sets a definite limit to the profits which can be made by any given agricultural methods from that area.

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[1] This is apparently true also of Professor Dewing's well-known "law of balanced return" in manufacturing expounded in Chapter II of Book IV of his *Financial Policy of Corporatons.* This law is stated on p. 42 as the proposition that "The ratio between the quantitative values of labor and fixed capital in any unit of product determines the point at which increase in the scale of total production ceases to be economical; i. e., it determines the point of maximum productivity beyond which further increments of labor cease to yield the same proportionate quantity of product." This last exposition is expressed in terms of marginal physical returns. The one first given in the quotation and many remarks of Professor Dewing's indicate that it is really profits that is meant. *Cf.* Dewing, *The Financial Policy of Corporations* (New York, 1922).

There is another aspect of the question which remains to be discussed. It is the profit of the operations of a farmer as a whole. No one thinks that the fact of physical diminishing returns in gasoline engines or cattle acts as a limit in any way on the profits of a farmer. It is a matter of common experience that this sort of diminishing returns can be evaded by securing larger gasoline engines or more cattle.

Can this sort of evasion be used against falling profits from a given area of land? Experience seems to show that it can " up to a certain point ". This is particularly true of the farmer who has a very small holding and is trying to engage in a type of agriculture which requires a good deal of equipment. Such a farmer is likely to have high costs because of the overhead costs of this equipment. He is compelled to have a larger amount of equipment per acre than the farmer who has a larger area. This is shown by a recent English work on the advantages of large and small holdings.[1]

The only alternative to relatively large investment in equipment is to borrow the equipment of neighbors after they are through with it. This, however, results in the delay of essential operations and reduced production. Hence, under the same conditions, the small farm is likely to produce less crop per acre. A comparison of crop yields in Mecklenburg and Bavaria shows that this is so.[2] In the former country sixty per cent of the farm lands is in holdings over 250 acres in size, while in the latter seventy per cent is in holdings under 50 acres. The soils are not markedly different in character.

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[1] Levy, *Large and Small Holdings,* pp. 156-180.

[2] Claphan, J. H., *Economic Development of France and Germany, 1815-1914,* quoted in Venn, J. A., *Foundations of Agricultural Economics,* pp. 69, 70.

COMPARATIVE YIELDS ON LARGE FARMS (MECKLENBURG) AND SMALL FARMS (BAVARIA) 1902-1911, IN HUNDRED KILOGRAMMES PER HECTARE

	Rye	*Wheat*	*Barley*	*Oats*	*Potatoes*	*Meadow hay*
Mecklenburg	17.9	23.7	22.4	21.2	141.6	41.2
Bavaria	15.8	16.0	17.1	15.6	116.9	48.6

Rather than take such reduced yields, the small cultivator in England devotes most of his land to pasture, as shown by Levy.[1]

PERCENTAGE OF ARABLE LAND ON ENGLISH FARMS OF VARIOUS SIZES

Size of Holding	*Percentage of Arable Land*
1–5	26.87
5–20	24.70
20–50	33.31
50–100	42.48
100–300	47.92
300–500	53.09
500–1000	58.06
over 1000	53.90

As a consequence of the handicaps under which the small farm is operated, increasing returns can be secured up to a certain point as the farm area is increased. That there is a decided limit to such economies, however, is shown, for America, at least, by the rapid cutting up into smaller units of the large farms in the west and south. The most positive investigation of the relative profits per farmer on large and small farms in America was recently made in Missouri by the state agricultural experiment station. This state is one which has lost a sizable fraction of its farming population in the last thirty years, and in which the average size of farm has probably been increasing. Nevertheless, this investigation, which was based on statistics collected from many farms, shows that the labor income on the large farms is by no means proportional to their area.[1] The results of the investigation appear in the following table:

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[1] Levy, *op. cit.*, p. 178.

Relation of Size of Farm to Labor Income on Missouri Farms in 1916

Size Group	*Average Size*	*Labor Income*	*Labor Income per Acre of Increment of Farm Size*
40 acres or less	26.6	$146	5.49
41–80 acres	64.7	227	2.12
81–120 “	103.3	313	*2.23*
121–200 “	159.2	525	*3.79*
201–400 “	243.5	711	2.21
over 400 “	459.6	999	1.33

The column of marginal returns shows that while the increase of farm size is attended as a whole by diminishing returns, in the interval between 81 and 200 acres this process is reversed. This is indicated by the italicized figures. Some caution, however, should be used in drawing inferences from such a table for the reason that the statistical method here used does not make sure that the large and small farms are identical in every respect other than size.

Other investigations have shown, for instance, that the large-scale farmer is likely to be a much superior man in energy, common sense and education. This, of course, would keep the returns on the large-scale farms from falling as rapidly as they otherwise might. Similarly the profits of the large-scale farms might be kept up by more effective utilization of machinery and equipment. These and similar factors would retard the rapid fall of marginal returns which would have been encountered had the large and small-scale farms been exactly alike except in point of size.

In spite of all methods of delaying, or of factors which tend to delay, the diminution of marginal returns, a limiting factor seems to be always present. The same thing might be said of any industry, it is true, but in agriculture the limiting factor seems to come into operation at a much earlier period. Large-scale farms have been notoriously unsuccessful. No doubt several factors have combined to produce this effect, but one factor seems to be by all odds the most important. It is the difficulty of supervising the increased labor supply necessary for the operation of the large-scale farm. In manufacturing, the telephone and similar devices have helped to overcome the difficulty of supervision, but in farming these things cannot be used so effectively. As a result, units of labor added as the size of a farm is increased must, from the nature of the case, be employed at points more and more distant from the center of supervision, making their control more and more difficult. It is thus inevitable that its productivity should decline as the size of the farm is increased and that as a consequence there should soon be no profit in any further increase.

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[1] Bulletin 140, University of Missouri Agricultural Experiment Station, p. 10.

CHAPTER VII

THE PROBLEM OF SECULAR DIMINISHING RETURNS IN AGRICULTURAL DEVELOPMENT

THUS far in this essay the consideration of the subject of diminishing returns has related mainly to those aspects of the question which are timeless, technical and capable of being given a more or less definite factual treatment. We are now to consider the problem of secular diminishing returns, an aspect which has always been a matter of belief and a center of controversy. In spite of the risk of digressing from questions of fact to those of opinion, the discussion of this problem must be undertaken, for, in the opinion of many economists, the law of diminishing returns in agriculture is, in its most important aspect, a secular law. Thus Marshall, in the quotation given in Chapter I,[1] seems to define the technical aspect of the law of diminishing returns as little more than a premise for the proposition that " whatever may be the future development of the arts of agriculture, a continued increase in the application of capital and labor to land must ultimately result in a diminution in the extra produce which can be obtained from a given extra amount of capital and labor ".

In this sense the law of diminishing returns is the proposition that, if population continues to increase, the efforts of successive generations of men to produce food will be rewarded by steadily diminishing returns of crops raised in proportion to the labor and expense involved. Or, to put the proposition in another way, it asserts that unless present tendencies are reversed the productivity of agricultural labor will in the future decline from one generation to another.

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[1] *Supra*, p. 11.

This proposition can probably be regarded with accuracy as merely an improved way of stating the consequences of the supposed natural process of over-population. Theories of over-population have always rested on two general propositions: (1) we can count on population increasing; (2) we can not count on production increasing proportionately. The second of these propositions has been the more difficult to establish. As is well known, Malthus based his argument for it on the supposition that, in the case of food supply, at least, production cannot be increased more rapidly than in an arithmetical ratio. As it was impossible to give any logical or factual support for this "law", believers in the process of over-population a century ago seized upon the recently discovered fact of diminishing marginal physical returns as a substitute, and upon it based their claims that production cannot keep pace with population. Instead of the original predictions of famine, disease, war and pestilence as a consequence of over-population, there was now substituted the less colorful but more scientific prophecy of secular diminishing returns.

Among economists, at least, this prophecy has in recent years largely lost the devoted following which it once enjoyed, and a reappraisal of the proposition in all of its ramifications seems to indicate that it deserves its fate. In the first place, so far is the law of secular diminishing returns from being a universal law of human development that not a single statistically proved instance of its operation seems ever to have been discovered. This is not because no attempt has been made to find such an instance. Believers in secular diminishing returns have often been challenged to produce such an instance, but to date seem not to have been able to do so.

The reason for this failure to produce an instance of secular diminishing returns in agriculture is that all the available evidence indicates that secular increasing returns have been the rule in human development. To illustrate this, it would be perhaps best to turn to the very place in which, it has been asserted, secular diminishing returns are most certain to occur.

It is the new country. " Consider ", writes West, " the case of a new colony; the first occupiers have their choice of the land, and of course cultivate the richest spots in the country: the next comers must take the second in quality, which will return less to their labor, and so each successive additional set of cultivators must necessarily produce less than their predecessors." [1]

Let us see how these speculations agree with the facts of America's economic development. It is certainly true that where conditions of safety and accessibility are equal, as well as where the work of clearing the soil and perhaps marketing the product are substantially the same, the richest soils *should* be occupied first, and consequently the soils occupied later *should* yield less returns per acre. That this has actually happened in the development of Kansas is shown by some figures presented by Professor Spillman.[2]

CROP YIELDS IN KANSAS, BUSHELS PER ACRE

Period	*Corn*	*Wheat*	*Oats*
1860–1889	34.2	15.3	32.8
1889–1908	21.6	11.8	21.9

The decline of yields seems to have been entirely due to the fact that the soils first occupied were in the fertile river valleys of the eastern part of the state, while the soils in cultivation in the second period included the vastly greater areas of less fertile land in the western part of the state.

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[1] Edward West, *Essay on the Application of Capital to Land,* (London, 1815), p. 6.

[2] Quoted in Hopkins, *Soil Fertility and Permanent Agriculture* (Boston, 1910), p. 330.

Such facts, however, do not prove that the yields *per man* have fallen off. It is right here that West apparently makes a logical error. Experience shows that poorer soils are usually cultivated in larger areas, and by other and less intensive methods, than the better soils and, other things being equal, yield substantially the same *per cultivator*.

That the more thorough agricultural exploitation of the country generally has not been accompanied by any decline in yields per acre may be shown readily by statistics which the Department of Agriculture and others have collected.

AVERAGE YIELD OF LEADING CROPS IN NEW YORK STATE,
BUSHELS PER ACRE

Period	*Corn*	*Wheat*	*Rye*	*Oats*	*Buckwheat*	*Potatoes*	*Hay, lbs.*
Year–1845 [1]	25.72			26.72			
1862–70 [2]	30.20	14.93	15.15	30.32	19.77	103.1	2516
1871–79 [2]	32.94	14.87	13.91	32.96	18.42	81.7	2404
1880–87 [2]	29.60	14.91	12.00	28.83	13.26	77.4	2225
1910–19 [3]	36.50	20.80	17.5	32.8	19.1	94.0	2620

The smallness of the crops for the period 1880-87 is to be attributed to less intensive cultivation resulting from the falling grain prices which accompanied the opening up of the great grain areas of the west. The table shows that in only one of the leading crops has there been any decline of production per acre in New York State in the last sixty years, but that in several there has been a substantial increase.

That there has been no decline for the whole country in the per-acre yields of our leading human food crop is shown in the following table: [4]

[1] Average of five districts cp E. Emmons, *Natural History of New York*, pt. v, vol., i, p. 326.

[2] From N. Y. Agr. Exp. Sta. Report for 1889, p. 32.

[3] From Yearbook U. S. Dept. of Agr. 1919, *passim*.

[4] Data from Yearbooks of U. S. Dept. of Agr., 1909, p. 450; 1915, p. 425.

YIELDS OF WHEAT IN THE UNITED STATES, BUSHELS PER ACRE

Period	*North Atlantic States, Me., N.H., Vt., Conn., N.Y., Pa., N.J.*	*South Atlantic States, Del., Md., Va., N.C., Ga., S.C.*	*East North Central States, O., Ind., Ill., Mich., Wis.*	*West North Central States, Minn., Iowa, Mo., N.D., Neb., S.D., Kan.*
1866–75	13.7	8.9	12.3	13.1
1876–85	14.1	8.9	13.9	11.9
1886–95	14.1	9.0	14.2	13.0
1896–1905	16.3	10.6	13.3	13.0
1906–1915	21.5	12.6	16.7	14.5

A still more general indication of secular increasing returns in American agriculture is afforded by the following statistics:

RELATIVE GROWTH OF POPULATION AND AGRICULTURAL PRODUCTION IN THE UNITED STATES, 1850-1920

	Population of U. S., Millions		*Production of Leading Crops (000,000 omitted)*					
			Wheat, bu.		*Corn, bu.*		*Cotton, bales*	
	Total	*% inc.*	*Total*	*% inc.*	*Total*	*% inc.*	*Total*	*% inc.*
1850	23.2		100		592		2.5	
1880	50.2	116	498	398	1717	190	6.6	164
1900	76.0	51	522	4	2105	23	10.1	53
1920	106.4	40	787	49	3232	53	11.4	13
1850–1920		359		687		446		356

It will be observed from this table that the largest increase in any of our crops was in wheat, the most important from the point of view of human food. Its increase was nearly twice the increase in population, and because the increase in total population was much greater than the increase in agricultural population, food production per agricultural worker more than trebled during the seventy years covered by these data. The only one of the three crops not to keep pace with the growth of population was cotton, not a food product. This is particularly interesting in view of the fact that the prediction of secular diminishing returns for the whole of economic activity was based on the assumed certainty that it would appear first in the production of foodstuffs.

The fact that American agriculture is experiencing secular increasing returns was brought out a few years ago in a public address by the Secretary of Agriculture.[1] "Production", he said, "has also kept up with the increase of population. Fifty years ago, or during the period from 1856 to 1874, the average production of the six principal cereals was 38 bushels. From 1905 to 1914 it was 52 bushels, an increase of 14 bushels." . . . "Farm workers have increased in numbers from 5,900,000 in 1870 to 13,700,000 in 1919, and the production of each farm worker in terms of the six leading cereals has also increased. In the period from 1856 to 1874, each farm worker produced an average of 266 bushels annually. In the period from 1906 to 1914, the average was 406 bushels, while in five years, 1915 to 1919, the average production per farm worker was 418 bushels."

In recent years many persons in the state of Missouri have been dismayed to note the decline in the agricultural population of the state. Most of them have concluded that the soil of the state is exhausted and that farmers are moving to newer soils. Mr. Paul W. Brown, editor of *America at Work,* investigated the facts of the situation and discovered that eighteen of the twenty counties which lost population in the decade ending 1900 were in the richest soil areas of the state. While farm male population of the state continued to decline from 1900 to 1920, a comparison of the yields in the five years before 1900 with those of the five years before 1920 showed the astonishing fact that the total production of oats had increased 90 per cent, wheat 115 per cent, and cotton 136 per cent.

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[1] Secretary Meredith, before the Merchants' Association of New York, Feb., 1920.

These facts leave no reasonable ground for believing that American agriculture is experiencing secular diminishing returns. They are, however, so well known that apologies for their presentation would be due the reader were it not for the fact that several men of high standing in the country have been trying assiduously in the last few years to persuade us to the contrary. Professor East, for instance, in his *Mankind at the Crossroads,* p. 168, states: "The reserve of virgin soil [of the United States] approached an end in quantity, or what amounts to the same thing, decreased markedly in quality between 1890 and 1900. Since that time there have been diminishing returns in agriculture in the sense that a given amount of capital and of labor has produced constantly less and less." The above statistics make it difficult indeed to accept this statement as a fact.

There are some persons who become convinced that secular diminishing returns threaten our agriculture when they discover that the production of agricultural products is not increasing as rapidly as the production of manufactured goods. The reason for this, however, is that the capacity of man to consume food is limited by the size of his stomach, whereas his capacity to consume automobiles, for example, has no physical limit. Even now, the growth of agricultural production has exceeded the growth of the size of the collective human stomach by just enough to cause disastrously low prices, and farmers are consequently seeking by means of some sort of agreement to curtail production.

No demonstration of the non-existence of secular diminishing returns in agriculture would be complete which failed to investigate conditions in old countries. For here too, it is alleged, the phenomenon is to be observed. So convinced is Professor East that the agriculture of old countries exhibits diminishing returns to labor that he asserts that total returns per acre have fallen off. "In most cases," he says, "it is not centuries but decades before continuous cropping shows decreasing returns, no matter what the rotation."[1]

Let us see how this has worked out in Europe. Kellerman's figures[2] for yields in Schmalzfeld, Germany, contradict it directly.

Crop Yields in Schmalzfeld, Germany, Bushels per Acre

Year	*Wheat*	*Rye*	*Barley*	*Oats*
1552–57	12.5	13.2	14.2	14.8
1670	14.6	17.2	16.1	17.4
1822	18.7	24.3	33.7	26.2
1860	35.3	39.3	32.9	62.9
1870	27.6	20.4	45.8	46.6
1887–96	40.0	29.6	47.6	59.7
1897–1904	46.1	34.0	50.4	69.1

These figures show the variation in crop yields arising out of good and bad seasons, but the trend is unmistakable. The great increase of yields in recent years is no doubt partly due to the tariff, but there can be no question that if medieval conditions of self-sufficiency were restored, grain prices would rise enough to encourage even greater yields than those shown above.

That these yields are not exceptional will appear from the history of the yields of several crops in the village of Rittergut Trebsen, near Leipsic. These figures are more reliable because periods rather than single years are used, though they do not cover as many centuries.

[1] *Scientific Monthly*, vol. 10, p. 615, June, 1920.

[2] From Hopkins, *Soil Fertility and Permanent Agriculture* (Boston, 1910), p. 326.

HISTORY OF THE YIELDS OF VARIOUS CROPS AT RITTERGUT TREBSEN, GERMANY[1]

Year	*Wheat*	*Rye*	*Barley*	*Oats*
1766–1775	13.25	12.33	21.71	23.48
1776–1785	16.63	14.47	20.44	23.45
1796–1800	13.89	15.36	15.16	17.90
1845–1849	25.51	28.75		56.25
1893–1894	29.85	28.36	30.95	54.74
1900–1904	36.14	32.52	43.23	57.80

The lesson taught by these figures is so clear that comment would be superfluous. For our purposes, however, the main issue is not whether yields per acre have been falling off in old countries, but whether yields per agricultural worker have been doing so. It is unfortunately much more difficult to get data bearing on this question.

As long ago as 1837, H. C. Carey, the American economist, writing in his *Political Economy,* argued that "It is entirely impossible to read any book treating of the people of England in past times without being struck with the extraordinary improvement of the means of living—with the increased facility of obtaining food, clothing, and shelter, and with the improved quality of all—enabling the common laborer now to indulge in numerous luxuries that in former times were unknown to people who might be deemed wealthy."

Not only had welfare improved, according to Carey, but at the bottom was the basic fact that labor had become more productive. "In 1389, in securing the crop of corn from two hundred acres, there were employed 250 reapers and thatchers on one day, and 200 on another. On another day in the same year 212 were hired for one day to cut and tie up 13 acres of wheat and one acre of oats. At that time 12 bushels to the acre were considered an average crop, so that 212 persons were employed to harvest an average crop, an operation which could be performed with ease in our time by half-a-dozen persons." [1]

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[1] From Hopkins, *op. cit.*, p. 327.

A few years later the powerful influence of J. S. Mill came to the support of those who disbelieved in the existence of secular diminishing returns to agricultural labor in the development of England. In his *Principles of Political Economy* he gave the traditional account of the forces producing the "tendency" to secular diminishing returns in agriculture, but added that this tendency is liable to temporary supersessions and that it had been counteracted throughout the history of England by the progress of civilization.

It is easy now to see that the circumstances which convinced England's leading economists in 1815 that the country was experiencing secular diminishing returns in its agricultural development really had little to do with the population problem. The acute misery of the proletariat in the rapidly growing industrial centers was apparently due not to over-population but to the Napoleonic Wars which were then going on. The blockade of the British Isles instituted by the Berlin and Milan decrees had become sufficiently effective to cut off the market for British textiles on the one hand, thus causing factory shut-downs and unemployment, and on the other to stop the importation of European grain. The high prices of grain which ensued made it difficult for the unemployed to get sufficient food and also had the effect of making it profitable to cultivate the poorer soils which previously would not have repaid the expense. That these things were due to the war and not to the working of an alleged inexorable economic law is shown by the fact that they disappeared when the war ended.

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[1] Quoted from Cannan, *Theories of Production and Distribution* (London, 1917), pp. 174-175.

The surest proof of secular increasing returns in English agriculture is found in the advance of the real wages of agricultural laborers. For it must be remembered that real wages measure roughly on the one hand what the employer thinks the laborer can produce, and on the other what the employee thinks he cannot produce if working for himself. The earliest available figures show that in 1300 the English agricultural laborer received a daily wage equivalent to about seven pounds of wheat. By 1400 it was twenty pounds, and by 1500 twenty-eight. During the next three centuries a good part of this gain was apparently lost. This may possibly have been due to the great rise of prices after the discovery of America, a circumstance which always reacts unfavorably for the worker. There is, however, no evidence from contemporary events that there was at this time any general reduction in the welfare of the masses. The real explanation of the fall in real wages is probably to be found in the fact that the growth of the domestic system of clothing manufacture about this time made it possible for the worker to support himself partly by spinning.

After 1850 the grain wages of the English agricultural laborer advanced rapidly. By 1880 he was getting nearly thirty pounds of wheat for his day's labor. At the outbreak of the world war, miserably paid though he was, he would have received on the average thirty-five pounds of wheat per day if all his rewards had been commuted into that grain.

The long-run economic development of old as well as of new countries, if we may judge by these two samples, seems thus to show that secular increasing returns, and not diminishing returns, is the law of recent human history. This conclusion is not weakened by the well-known fact that for short periods diminishing returns can frequently be found.

Every period of bad crops or business depression is likely to provide examples of population increasing and production falling. Wars, epidemics of disease and natural catastrophes often have the same effect. Experience generally shows, however, that when normal conditions are restored production increases so rapidly as to make longer periods show increasing returns.

Assuming that these generalizations are true of the western countries for the last few centuries, what evidence is there that they are applicable for other parts of the world and for longer periods of time? What, for instance, has been the trend in China? It is often accepted by Occidentals as self-evident that China is over-populated. This opinion, however, is sharply challenged by certain students of the Orient. These authorities point out that mere density of population is not in itself sufficient evidence of over-population, and that the difference in standards of living between China and the western countries is not due to their decline in China but to their phenomenal advance in the western countries. Chinese standards of living are, in fact, about the same as those of all those parts of the world which are as yet untouched by the Industrial Revolution and most of which are incidentally very sparsely inhabited.

That the apparently stationary condition of China and many other unprogressive parts of the world is really one of progress at an unusually slow rate is increasingly indicated by archæological discoveries. There is hardly a country in which have not been found evidences of former inhabitants who lived a technologically inferior type of economic life and very probably a less productive one. It is true that there are striking evidences of cultural decay in many spots, but archæologists seem inclined to explain these wrecked or abandoned civilizations on the basis of climatic change or military spoliation rather than population growth.

Whatever may be true of particular areas for short periods of time, the law of human change as a whole seems to have been one of advancement.

This, however, in the minds of most economists, has little to do with what will happen in the future. The prophecy of secular diminishing returns in the future has never, to the writer's knowledge, been based on the claim that it had been the rule in man's past. It has been based entirely on a supposed law of human biology, the law enunciated by Malthus that human populations, unless restrained by external forces, grow naturally in a geometric ratio.

Of all the doctrines of Malthus, this law has been least denounced. Its mere statement has generally carried conviction. Yet, if it is true, the secular increase of returns which seems to have characterized man's past must sooner or later give way to secular diminishing returns. It is necessary, therefore, before proceeding to make some examination of its validity.

The law of the geometric growth of unchecked populations has always had its main support in human reason. Attempts have been made from time to time to get illustrations of its operation from the statistics of population growth, but these statistics usually show so clearly the complex nature of population growth as to weaken rather than strengthen the case for the law. Malthus, for instance, thought he could prove from estimates, and later censuses, of population in this country from 1750 to 1810 that our population was doubling from native growth every twenty-five years. It was shown by Godwin, however, that his allowance for immigration had been inadequate, and recent students have shown that the period of doubling of native-born population is increasing so rapidly that it may soon reach infinity.[1]

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[1] *Cf.* Jefferson, Mark, "Looking Back at Malthus," *Geographical Review*, April, 1925.

It is likewise impossible to verify the geometric law experimentally. Micro-organisms may be made to multiply with extreme rapidity under certain circumstances, it is true, but their rate of multiplication is quickly slowed down by factors analogous to the " checks " to human population.

In the last analysis, the chief support of the law of the geometric increase of unchecked populations is its inherent reasonableness. Man, like other species, is equipped with a reproductive capacity far in excess of what is required to maintain numbers. It is not unreasonable to suppose that it is natural to exercise this capacity to its full extent. If it is exercised to any extent greater than that which is required to maintain numbers, and this extent remains the same from one generation to another, as it is reasonable to suppose that it will, then a law of geometric growth is automatically in existence.

Clear and compelling as this proposition is, doubts have been raised regarding a number of its underlying features. It has been questioned whether reproductive capacity actually does remain the same from one generation to another, and also whether the inclination to use this capacity is really the fixed quantity it is supposed to be. These questions are obviously beyond the scope of the present discussion and cannot be considered here.

More germane to the present discussion is the criticism that it is idle to speculate as to what would happen if the " checks " to population growth were not in existence. " The world," says Schuchert, " is, . . . and always has been fully populated ". If we except that dubious period when life first appeared on the earth and some brief periods following the rare disturbances in the balance which everywhere exists between the numbers of different forms of life, this statement is difficult to deny. The first forms of life known to have appeared on the earth were of those orders which have the highest fecundity. The earth must have been fully populated with them in a period of time which, considering the eons of history of life on the earth, might be considered almost infinitesimal. All the thousands of species which later appeared must have made their gradual emergence in an environment crowded with enemies. Arguing about how rapidly species would multiply if there were no checks may thus be compared, not unfairly, perhaps, to discussing how rapidly the earth would fly apart if the law of gravity were to disappear. The former condition is nearly as unlikely to occur as the latter.

These considerations indicate that the real issue between the prophecy of secular diminishing returns and the expectation of a continuance of secular increasing returns is a difference of opinion as to which of two pictures of the past development of man is the correct one. Behind the prophecy of secular diminishing returns is the picture of man as having originated at a definite spot on the earth less than ten thousand years ago and as having spread from this point over the surface of the earth, overcoming one by one the obstacles to his movement, till he is now reaching the last habitable areas of its surface. From now on, as population increases, it will be possible to get the greater amounts of food required only by working existing farms more intensively. On account of the fact of physical diminishing returns this will mean smaller and smaller increments in product as further increments in labor and capital are applied. In other words, there will be a secular diminution of the average physical returns to labor.

Behind the expectation of the continuance of secular increasing returns is quite another picture of man. He is thought of as having, like other species, changed gradually during a very great period of time till his form is now quite unlike that of his remote ancestors. Instead of an ancestral pair of men there is a large ancestral group. Instead of a single point of origin it is thought probable that during the hundreds of thousands of years of man's emergence many, if not most, suitable parts of the earth's surface have been inhabited. Instead of having originated in a world containing enormous room for expansion, man is thought of as having, during the long period of his emergence, been continuously exposed to the earth's ancient condition of over-population. Instead of developing rapidly toward increasing population pressure, he is thought of as growing because of his increasing control over the forces of nature, ever more rapidly toward a condition of freedom from it.

Between these two theories the choice should not be difficult. It is true that the first is more readily comprehensible, more widely supported, and thoroughly intrenched still in the unconscious thinking of most educated people. But the latter has behind it even greater authority. The earth itself, which has been aptly described as a great book which those who will can read, bears on its surface ample evidence of the general accuracy of the developmental theory.

An even stronger evidence, if possible, is the story of human invention. If one believes that the first inventions made by man occurred a century and a half ago, it is quite logical to suppose, as is often done, that we are living in the midst of a wave of invention which will soon pass and leave us in the midst of the stationary state. If, on the other hand, we believe that inventions have been occurring for thousands of years and that they are constantly increasing in number, it is hard, indeed, to believe that they are now about to come suddenly to an end.

There is abundant evidence that the latter view of invention is the correct one. At the risk of digression some small part of this evidence may be summarized here. It should be noted, however, that the period covered by the history of progress in invention varies considerably with the field.

The longest record of progress can be written for the cutting tools. More than 100,000 years have elapsed since it was discovered that stone could be chipped to make efficient implements. Obvious improvements in these tools had been made by 50,000 years ago. A marked change occurred about 12,000 years ago when the art of grinding and polishing granite was discovered. This invention ushered in the new stone age. This period of human progress came to a gradual end about 5000 years ago when copper and later bronze began to be used as tool materials. These in turn lost their importance in the river valley civilizations of the old world a little over three thousand years ago when iron came into use. Iron, finally, was replaced by steel after 1865 when the Bessemer process of steel manufacture came in, and we are now living in the age of steel. A review of this record will support the conclusion that not only have inventions occurred at all stages of human development but that the rate of progress is accelerating.

In view of the fact that the prediction of secular diminishing returns is based on the assumption that invention in agriculture is quite unable to keep up to an automatically expanding population, it is a matter of some importance to trace the history of agricultural inventions. There are some processes where this is quite easy to do. Take, for instance, harvesting. The most primitive method of getting the grain from standing stalks is to hold them over a basket and beat them with a stick. A step in progress was made when it was discovered that it was advantageous to pull off the heads and knock out the grain *en masse* on a threshing floor. Experience then showed that it was easier to cut the stalks than to pull off the heads. It was perhaps as early as 5000 B. C. that the Egyptians invented, for the purpose of doing this, a wooden sickle armed on the inner edge with a row of flints. The discovery of metals led to the development of practically the present type of sickle by 1000 B. C. The next step was the invention of the scythe. This was in common use in Europe in the sixteenth century and was perhaps invented many centuries earlier, judging from the shape of certain blades which have been found. It made it possible to cut grain much faster because it brought the powerful leg and back muscles to the assistance of those of the arms in actuating the cutting blade. The scythe was much improved by the addition of an attachment to catch the cut grain when the cradle was invented in 1803. Finally, a series of inventions in the middle of last century culminated about 1880 in the perfection of the modern harvester.

It will probably be objected at this point by the confirmed believer in secular diminishing returns that all these inventions have made it easier to collect the grain which grows on an acre, but that they have not made more grain grow on that area, and that in spite of them human welfare is in peril on account of the automatic increase in population.

Perhaps the easiest way to answer this objection is to point out that cereal culture marks merely one step in the development of means of extracting food from the soil. Man is supposed to be descended from a ground-living ape and for countless ages probably lived on the edible roots, tender shoots, fruits, berries and nuts which can be found in most parts of the world. Perhaps the most primitive method of cultivation found among men is what is called migratory agriculture. It is carried on in wooded regions and involves periodical clearing of the land by cutting down trees and burning the trunks with the brush during the dry season. Seeds of different kinds are planted together in holes dug with a pointed stick between the charred trunks and stumps.

As the young plants come up they are allowed to struggle for themselves against the growth of weeds which soon appear. After several crops have been raised the land is abandoned to the weeds and undergrowth and a new plot it cleared. After from five to twenty years, the old plot, though now covered with trees of considerable size, will again be cleared and cultivated. The productivity of this system is naturally difficult to estimate. It never yields much more than enough to keep its practioners alive, and considering the whole area used, the product per acre cannot be the equivalent of one bushel of grain.

The domestication of wheat and barley, rye and oats in the new stone age created an entirely new agriculture. It now became highly advantageous to have the fields completely cleared, repeated cultivation make plowing advantageous, and gradually the advantages and methods of fertilization were discovered. The great productivity of this system laid the material foundation for all the ancient civilizations.

We are still in the cereal stage of human evolution. During the last century the productivity of cereal culture has been greatly improved by the discovery of new systems of crop rotation, new methods of fertilization, and new labor-saving machinery. The machinery alone during the last century cut down the labor cost of a bushel of wheat in the United States from 133 minutes in 1830 to 10 minutes in 1904. Improved varieties of cereals have been produced. For instance, the crossing by Saunders of Red Fife wheat with Hard Red Calcutta at the Canadian Agricultural Experiment Station in 1893 produced the new variety known as Marquis. This wheat, because of its early maturing characteristics, high yields and excellent milling and baking qualities, has been a godsend to Canadian wheat farmers. It has pushed the wheat belt several hundred miles northwest and has increased the Canadian wheat crop by many millions of bushels.

There are still many new avenues of progress for cereal culture. Says Professor J. Russell Smith, one of the world's greatest authorities on food production, in his recent volume *The World's Food Resources,* "With present knowledge it is certain that the now-recognized wheat belt of central United States and Western Canada is good for an increase of several hundred million bushels of wheat per year, perhaps a billion, possibly even more. It depends chiefly on the price." Furthermore, "The Siberian belt is even longer than the Canadian, and may possibly produce more wheat. At present there are not in all Siberia more than 5,000,000 white people. The region has, beyond any reasonable doubt, possibilities of an increase of hundreds of millions of bushels of wheat." These views of Professor Smith's have recently been ably supported by Mr. O. E. Baker, Agricultural Economist with the United States Department of Agriculture, who estimates a potential world production of 12,150,000,000 bushels of wheat, nearly four times the actual production of recent years.[1]

In spite of these possibilities of greatly increased cereal production, there are some signs that we are nearing the end of the cereal stage of civilization. The time is not far distant when the white man will greatly enlarge his present outposts in the tropics. When he does so he will probably find other crops more advantageous than the cereals. Even in temperate regions Professor Smith suggests that tree crops would be vastly more productive than the cereals. It is well known that wild acorn trees supported a dense Indian population in the state of California. The time may come when as much attention will be paid to the breeding of high-grade, high-yielding varieties of nut-bearing trees as is now given to grains. It is certain that the nut and fruit bearing trees, and plants of the potato variety have the ability to produce quantities of food per acre greatly beyond the capacity of the cereal plants.

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[1] *Economic Geography,* vol. i, no. 1, p. 48.

An interesting possibility of future increased food production arises out of the consumption of coal. It is well known that all the carbon in plants is extracted by them from the trace (0.03%) of carbon dioxide in the atmosphere. It has been shown by biologists than an increase in the concentration of this gas around plants causes a rapid increase in their rate of growth. At the present rate of consumption of coal, the concentration of carbon dioxide (which results from its burning) in the atmosphere will be substantially increased at no distant date. There seems no reason for doubting the claim that this will sometime cause an increase in the luxuriance of plant growth.

Probably the most revolutionary possibilities of increased food production lie in the field of organic chemistry. Nearly a century has elapsed since the first organic compound was artificially made out of inorganic materials. The hope has frequently been expressed that chemists will one day be able to make artificially the proteins, carbohydrates and fats on which man is chiefly dependent for food.

The question as to whether or not this can be done is of course a matter on which none but chemists should speak. Mr. Carl L. Alsberg in a recent number of *Industrial and Engineering Chemistry* declares that "the problem is far from hopeless. No one would venture to predict when the theoretical and experimental problems will be solved. The solutions may be nearer than most men think."

"The synthesis of simple sugars and of fats presents no insuperable difficulties to the organic chemist of the present. To be sure, the synthesis of complex carbohydrates like starch and cane sugar is still beyond his powers; but their synthesis is not necessary, for such carbohydrates must be converted by the digestive juices into simple sugars before man can absorb and use them. That simple sugars can be made synthetically in the laboratory—at least in their optically inactive form—is common knowledge among chemists."

"The situation is no different in regard to fats. That glycerol and fatty acids, the components of ordinary fats, can be made in the laboratory is also common knowledge, even though the production of neutral fats from them is not easy. The fats, like the complex carbohydrates, must be split by the digestive juices before man can absorb and use them. In the case of fats this splitting takes the form of conversion into glycerol and soap."

"The synthesis of proteins is not so simple, for they possess certain biological characteristics not yet reproduced in the laboratory. It is now well established, however, that large quantities of protein are not essential to the nutrition of animals, for protein nutrition is really amino acid nutrition. It has been shown that ingested proteins are not absorbed as such. They are completely converted in the digestive tract into simple crystallizable amino acids and these are absorbed into the blood stream.—Nearly all the amino acids from which proteins are constructed—there are probably not more than twenty-five—have already been synthesized. There is every reason to believe that before long all of them will have been so synthesized.—It is safe, therefore, to believe that the three groups of foodstuffs—carbohydrates, fats, and amino acids—can or shortly will be producible by artificial means." [1]

Laboratory possibilities are of course not the same thing as commercial possibilities. Experience has shown, however, in many instances of historic importance how the one can unexpectedly become the other. Population alarmists will no doubt brush aside these possibilities with a flourish, preferring to meditate exclusively upon their own pet possibilities of population expansion. The sober student of the problem will probably conclude that the one is as possible as the other.

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[1] *Industrial and Engineering Chemistry*, vol. xvi, no. 5 (May, 1924), p. 524.

At the risk of being too obvious, it may be pointed out before leaving this part of the subject that it is not up to those who reject the theory of secular diminishing returns to lay down a definite program of technical progress for all time to come. Their position is unassailable when they point out that technical progress is a continuous and accelerating feature of human development and that there is apparently no reason to suppose that it will not continue in the future. At each stage in human development there are many possibilities of technical advancement. Some of these are accomplished and some are not. It is impossible to say in advance which will be the successful ones. It is good that it is so. It gives the tang of adventure to those who watch the march of mind.

No account of the history of technical progress would be complete if it failed to point out the fact that invention is a nearly universal human trait. So far from Europeans having a monopoly of inventiveness, we find that several epoch-making inventions have been made in China. Furthermore several of the important steps in technical progress have been made independently in different places. The arts of making polished stone tools, of mixing tin with copper to make bronze, and of phonetic writing were independently discovered in the old and the new worlds. Remarkable parallels also exist between tool shapes developed in different parts of the world. All of which shows that when man is confronted by a technical problem, he is certain to seek a solution and quite likely to find one.

A final important feature of inventiveness is its versatility. This must be pointed out because the most popular means of disposing of invention used by believers in secular diminishing returns is to show that it cannot continue. It is computed, for instance, that if the present rate of increase of coal consumption is to continue, the world's whole coal supply will be used up in less than two centuries. Similarly, but for different reasons, it is shown that the present rates of increase of telephones, steamships, railroads, automobiles, etc., would, if continued, soon supply humanity with facilities far out of proportion to any need now conceivable. Progress in these things, it is said, cannot continue.

Such arguments, while conjectural, are probably sound. They neglect, however, the commonly observed fact that when inventiveness has for the time being mastered one field, it departs immediately for new and more promising fields. Thus, inventiveness in agriculture at one time manifests itself in the production of better grades of stock, at another in improved crop rotations, at another in better farm machinery, at still another in new and improved varieties of grain, etc. Similarly, the spurt of inventiveness in the spinning industry in the latter part of the eighteenth century was not maintained, but equally revolutionary inventions were soon being made in canal and railroad building, later in steel making, still later in internal combustion engines, and finally in airplanes and radio. Long experience shows, therefore, not only the continuity, acceleration and universality of inventiveness, but also its versatility.

The story of human invention, of which this is but a small part, thus seems to bring powerful support to the developmental picture of man. When added to the evidence from paleontology which seems to show that man evolved during a period of some thousands of centuries from a form closely resembling the apes to his present form, it seems to prove clearly that the trend of human development is not from underpopulation to overpopulation but rather from the universal animal condition of population to the limit to his present condition of increasing freedom from crowding.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

THE CONCLUSIONS (most of which are more or less tentative) which have been made in the foregoing pages have been so numerous that a general view of them may be desirable.

To start with, an attempt was made to show that the efforts of many economists to arrive at a permanent and satisfactory statement of the law of diminishing returns have been impeded by (1) the lack of a precise terminology, (2) the failure to keep distinct the three different sorts of phenomena, physical, entrepreneurial and secular, to which it has generally been attempted to apply it, (3) the failure to distinguish carefully between what are here called average and marginal returns, and (4) the failure to point out that returns to marginal doses of input are but a rough approximation of the ideal of marginal rates of return, and that they generally indicate that it is profitable to carry input further than it really is carried.

Perhaps the main conclusion of the present study would be that there is no one law of diminishing returns, but that in its place there must be at least three groups of statements, one each for the phenomena of physical, entrepreneurial and secular returns.

The experimental facts relating to physical returns which have been considered here seemed to indicate that the general trend of all sorts of marginal physical returns is downward. In many instances, more or less well-established stages of constant or even increasing returns were encountered, which, however, generally acted as only temporary interruptions of this trend. In some important instances input was carried to such an intensity that marginal physical returns became negative. In most, if not all, the other cases it seemed logical to suppose that if input had been carried this far, the same result would have followed.

Probably because of heavy internal energy expenditures, human and animal sources of power, internal combustion engines, and the animal mechanism when used as a means of converting inedible into edible food, exhibit average physical returns rising up to a certain point beyond which they show, but more slowly, the fall of marginal returns. In the process of fattening, both cattle and swine show secular diminishing (average physical) returns.

Coming now to entrepreneurial or money returns, it was pointed out that the point of most profitable input of any particular productive factor can be found by determining where the curve of marginal money returns falls below unity, or, more easily, by determining where the slope of the curve of total physical returns falls below the ratio of the cost of a unit of input to the value of a unit of output.

In studying the variation of money returns from a particular area of land we are compelled to take account of overhead costs such as rent of land, cost of plowing, harrowing, seeding, etc. The burden of these costs is so heavy that early increments in the rate of applying fertilizers etc. to the soil yield increasing average money returns, in spite of diminishing marginal physical returns.

The curve of profits is always anticlinal in character, that is, it rises up to a certain point and then falls. It is here apparently that the classical argument about returns increasing up to a certain point is applicable. The "certain point" is where the curve of marginal money returns falls below unity. The curves of average money returns and profits are invariably anticlinal, but the crest of the former is reached at a smaller amount of input than the latter.

Diminishing physical returns are responsible for finally diminishing profits from a given area of land. The most important factor limiting the profits to be secured by enlarging the area of a farm is apparently the tendency toward growing inefficiency of supervision, and hence diminishing returns as the size of the farm is increased.

The chapter devoted to the ever-present problem of secular diminishing returns brought forward a good deal of evidence to show that in the past secular increasing returns have been the rule in agriculture. It then brought out a number of weaknesses in the arguments which have been commonly used to show that secular diminishing returns are almost certain to occur in the future. In particular, the conclusions commonly drawn from the Malthusian law of the geometric growth of unrestricted populations were shown to be untenable for the reason that these conclusions generally assume that human life has but recently appeared on the earth. Paleontology, however, is revealing to us a biological world of great antiquity—a world in which species gradually come into existence in a world already packed to the limit with other species. Their chance of survival depends entirely on superior adaptation to environment, superior capacity for offense or defense, or superior fecundity. The last superiority often makes up for shortcomings in the others. The high fecundity of a species, therefore, instead of proving that it is natural for the species to multiply rapidly, is probably to be regarded merely as an indication that the young of the species live in a very dangerous environment in which the parents are incapable of protecting them. To argue about how rapidly a species would multiply if all restrictions on its growth were removed is to talk about a highly unnatural state of affairs—a condition which has never existed in nature except for brief periods following some upset, and which cannot be created in laboratories for more than the shortest periods of time.

To apply this argument to the present case, it seems obvious that man, like other species, evolved into a fully populated world. He has been able to survive in it, and indeed establish his ascendancy over it, because of his possession in large measure of the characteristic of inventiveness. The manifestation of this characteristic has, for the last few thousand years, at least, been accelerating, and unless this fairly well-established tendency is reversed, there seems to be little reason to fear that he will revert to the natural animal condition of population to the limit. In other words, it seems reasonable to expect a continuance of secular increasing returns.

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INDEX

Alsberg, Mr. Carl L., quoted, 87-88
Anticlinal average money returns, 59, 61, 62
Anticlinal profits, 56-66
Area of farm as affecting profits, 63-66
Arkansas Agr. Exp. Sta. experiment, 45
Average returns defined, 17
Average returns from marginal inputs, 19
Carey, H. C., quoted, 75, 76
Cereal culture, 85-86
Columella quoted, 44
Cornell Univ. Agr. Exp. Sta. experiment cited, 54-55
Cournot, Augustin, quoted, 15
Davenport, Prof. H. J., quoted, 12
Definitions of diminishing returns, difficulties, 11, 92; varieties, 12, 13
De Leonato quoted, 44
Diminishing Marginal Physical Returns: in application of fertilizers to the soil, 32-40; in application of seed to the soil, 41, 42; in the economy of the horse, 27-29; in the human body, 25-27; in internal combustion engines, 29-31; in meat production, 50-53; in milk production, 54, 55; in plowing and cultivating the soil, 42-46
Edgeworth, Prof. F. Y., quoted, 16-17
Future food possibilities, 84-88
Illinois Agr. Exp. Sta. experiment, 50-52
Increasing marginal physical returns "up to a certain point" discussed, 47-49
Invention, in agricultural implements, 83-85; in plant breeding, 85; in tool materials, 83; apparent universality of, 89
Inventiveness, versatility of, 90
Kansas Agr. Exp. Sta. experiments cited, 46, 53
Lang, Emil, 47
"Law of Diminishing Increment" discussed, 40
Limit of profitable input, 20-22
Logarithmic law of soil productivity, 47-48
Malthusian theory of geometric growth of unchecked populations, 79-81
Marginal rates of return, 20-21
Marginal returns, 18-23
Marshall, Prof. Alfred, quoted, 11
Meredith, Sec., quoted, 72
Migratory agriculture, 84-85
Mill, J. S., 9, 76
Missouri Agri. Exp. Sta. (Univ. of) investigation, 65
Mitscherlich, Dr. E. A., 47-48
Money (or entrepreneurial) returns, 13
North Dakota Agr. College investigation, 57-58
Ohio Agr. Exp. Sta. experiments, 36, 38, 41, 42, 46, 53
Overpopulation in China dubious, 78
Penn. Agr. Exp. Sta. experiment, 35
Physical returns defined, 13; tests of, 15-23; translatable into money terms, 56
Returns from marginal doses of input, 18
Rothamstead experiments cited, 34
Schuchert quoted, 80
Secular diminishing returns defined, 13, 67; discussed, 68-91
Secular diminishing returns in meat production, 53-54
Secular trend of crop yield per acre in Kansas, 69; New York, 70; Germany, 74-75; United States, 71

137204

Secular trend of crop yield per farmer in Missouri, 72-73; United States, 72
Smith, Prof. J. Russell, quoted, 86
Spillman, W. J., 40, 48, 49, 69
Synthetic food possibilities, 87-89
Total returns defined, 17
Tree crops, 86
Tull, Jethro, quoted, 43
Turgot quoted, 42
Utah Agr. Exp. Sta. experiment, 39
West, Edward, quoted, 10, 69
Young, Arthur, Fertilizer experiments, 32-33

P9-CYZ-042